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ABSTRACT

Computer assisted instruction, software design, and course organization are among the topics discussed in this varied, 15-paper collection which includes descriptions of specific projects, general essays and practical suggestions for improving or implementing computer-oriented instruction. The following papers are presented: (1) "Organization of Computer Based Courses"; (2) "Basic Mathematics in Colleges and Universities--Computers as a Solution"; (3) "Nontrivial, Nonintelligent, Computer Based Learning"; (4) "A Preliminary Taxonomy of Ways of Displaying Text on Screens"; (5) "Advantages of Computer Based Learning"; (6) "Computers and Information Technology as a Learning Aid"; (7) "Two Examples of Computer Based Learning on Personal Computers"; (8) "Computers in Learning--Common False Beliefs"; (9) "Graphics and Screen Design for Interactive Learning"; (10) "Compendium of Bad but Common Practices in Computer Based Learning"; (11) "Computers and the Future: Education"; (12) "A Tale" (describes development of a "marvelous invention"); (13) "Computer Assisted Learning--The Age of Reason"; (14) "Families, Computers, Learning"; and (15) "Using Computers for Training--Getting Started." Five papers provide references. (LMM)

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COMPUTERS & LEARNING: A COMPENDIUM OF PAPERS

by

Alfred Bork

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ORGANIZATION OF COMPUTER BASED COURSES

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April 26, 1983

The computer has been used as a learning device for more than a decade. Much use has been experimental, small scale at a few institutions. Now we are beginning to see more widespread use of computers; all indications are that this rate of increase will continue for a long time.

One important new feature is the beginning of commercial marketing of computer based learning material. A wide range of companies is entering the fray--textbook publishers, other publishers, computer vendors, and new companies developed just for this marketing task. Much of the material marketed is of poor quality, based perhaps on the assumption that when so little material is available, almost anything will sell.

Almost all modules marketed for the computer are "tidbits," small bits fitting into courses driven primarily by traditional learning modes: lectures and textbooks. The computer units prevalent so far assume such conventional courses. At the experimental level, however, we find much more extensive curriculum with the computer playing an important role in the structure of the course.

When a new learning mode appears the initial tendency is to use course structures already successful with earlier learning modes. This is the naive initial assumption of a successful developer of curriculum material within older learning modes such as books and films. But as experience increases, along with understanding of the learning capabilities of the computer, new overall organizational structures for courses emerge that were not possible without computers. This paper delineates organizational modes for computer based courses.

Implicit behind my discussion is the idea that computers can be very effective learning devices, particularly in large classes. I will not explore the effectiveness of computers in this paper; the reader should consult other sources.[1]

First, I consider general aspects of courses, some concerned with learner control and one with a variety of approaches. Then I describe course organizations made possibly by computers.

Content Choices

Most existing courses in every media assume instructor controlled content, where the instructor determines everything to be learned; students have little choice. Computers, from earliest days, have allowed courses where students enjoy flexibility in content. For example, the beginning physics course at Irvine depending heavily on the computer, has allowed, in different variants of the course, from two to six separate tracks through the ten weeks of the quarter. Two sets of material are available. The tracks in versions offering more choice are built from combinations of these materials. In each case a fixed set of student materials was available, but the topics of the different tracks differed significantly, as evinced by the different tests used with the two sets of materials.[2]

We could carry this further and allow still greater user control of content. Some of the staunch supporters believe that this is how LOGO should be used. At least in some cases LOGO devotees seem to object to the idea that *any* fixed curriculum should exist at all; rather they suggest that users should make all the choices of what to do next. I do not believe, however, that such completely free student content choice has ever occurred in school environments, except on a very small scale.

So we might think of learner control of content as a *spectrum*, starting with the usual courses with no control and moving through a variety of situations with more and more control on the part of learners. We could argue philosophically for various positions in the spectrum, but we will not. As with many of the issues raised in this paper, we need more experience and empirical information before we can make reasonable assertions.

Pace

Another degree of learner control concerns the pace of the course, the *rate* or speed at which students move through the topics of the course. Most traditional pre-computer courses offer little choice; the timing of lectures and dates of assignments and exams, establish a fixed instructor-determined pace. A student who tries a slower pace is penalized by the grading system, and no incentive encourages a faster pace.

A computer based course or curriculum can allow learner

control over pacing. The rate of learning can thus be different for different students. For example, a student whose mathematical background is indequate for a topic in chemistry can take the time to improve and then can return to chemistry. Or if students are already familiar with a topic, they can move through it quickly.

A possible psychological difficulty with learner control over pace is procrastination. It is conceivable that some students told to move at their own pace will do *nothing*! Whether this is a problem or not may depend on other factors in such courses.

Order of Topics

Just as the usual courses offer learners no choice in content or pace, so these typical courses usually offer learners no choice either in the *order* to approach topics. Again the fixed order is determined by developers or by instructors. Indeed, the behavioral approach to instructional design often seems to imply that this fixed order of topics is essential, with the behavioral emphasis on developing a sequential set of behavioral objectives.

But some approaches violate this fixed order and allow students to have some measure of control, perhaps even complete control, over the ordering of the topics. Gordon Pask champions this point of view, arguing that the best learners do not approach the learning task linearly, but rather typically study simultaneously several components of the subject area.

Instructors often believe strongly that students cannot or should not study Topic B until they have studied Topic A, so their implicit view is the linear view just discussed. But this is not necessarily the case for all students. So learner control of topics is again a spectrum, varying from no control to complete control.

Ways of Learning

Another possibility may be observed in curriculum developments employing the mastery learning ideas, with or without computers. The question is, for a given topic, how many ways do students have for learning that topic? Often only one approach is easily available; the textbook presents one way of learning the material, and the lecture, while using a different mode, often follows closely the textbook approach. So we have with textbook and lecture a difference in medium, but not a difference in approach; students have in most situations only one window into the topic being learned. A student studying alone, using a book, is even more restricted.

In the contrasting situation any one topic or concept benefits from a "supermarket" of ways for learning, employing different media and different approaches to the topic. Perhaps some structured way exists to gather the products students need in the supermarket of learning approaches, or perhaps it is left entirely to the student. Like all supermarkets, it can be relatively sparse or rich with many learning products.

What is the advantage of supermarket approaches? Benjamin Blum and other supporters of mastery learning ideas suggest that different students can best learn in different ways. That is, an approach which works well with one student will not necessarily work with another student. The claim goes further: For every student some way exists to learn the topic effectively and in reasonable time. Even further, some individuals would argue that if someone fails to do well in learning something, that person did not have the "correct" learning sequence available. The implication, then, is that students fail only because these students lack adequate curriculum material. This hypothesis needs to consider motivational issues, too--it is difficult for anyone to learn who is dead set against it!

The four factors discussed in the last three sections, fixed content versus learner controlled content, fixed pace versus variable pace, fixed order versus learner controlled order, and single versus multiple ways to learn, can apply in a variety of course ordering structures. In most learning situations today, the choices are (see Figure 1) for the small end left of each spectrum; little learner choice is offered. On the other hand, choices with too much freedom may be impractical for many learners.

Readers should consider each of them in the light of the next major section of the paper, which considers ways of organizing courses.

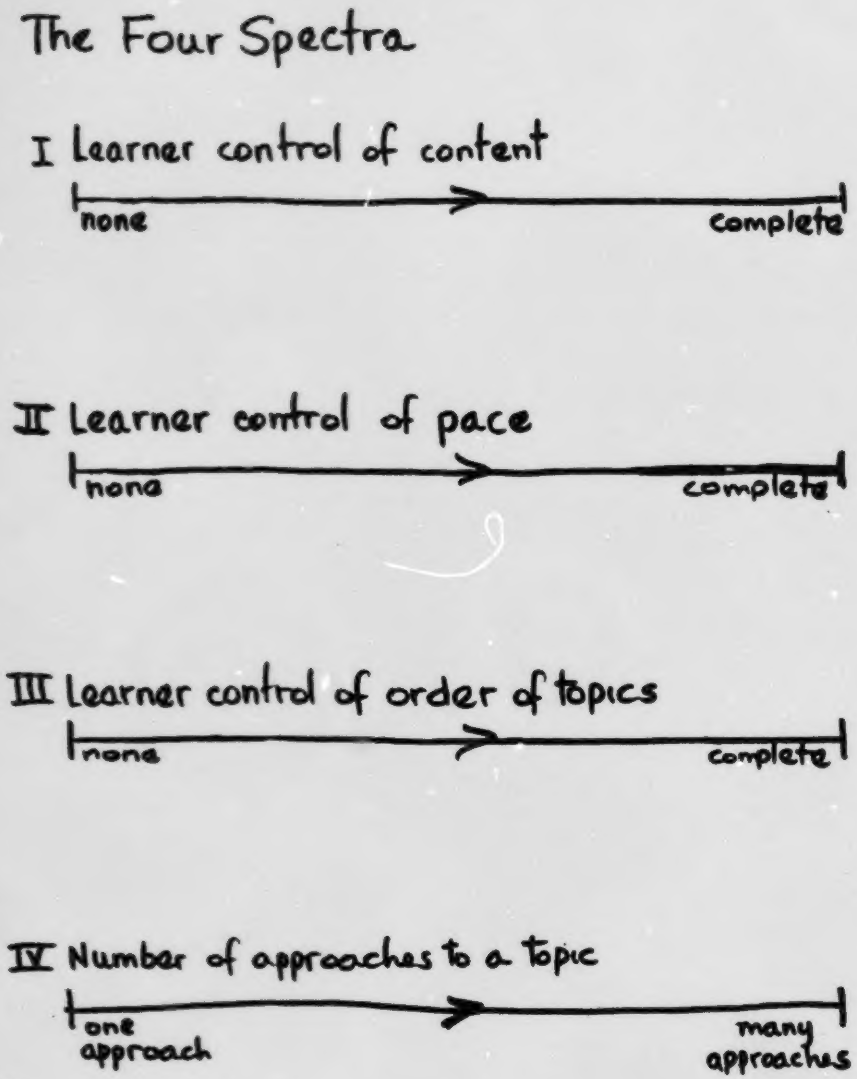
The Four Spectra
I Learner control of content
none
complete
II Learner control of pace
none
complete
III Learner control of order of topics
none
complete
IV Number of approaches to a topic
one approach
many approaches

Figure 1

Course Organizations for Computer Based Courses

1. Traditional Course with Computers

The first mode of organization is, by far, most prevalent when computers are used today. The organization of the course is like most non-computer courses, with the same fixed sequence of topics and with a fixed pace for all students. The computer serves an important part of the instructional process, but the organization of the course remains traditional.

The computer may replace or augment the book or the lecture. In either case the computer material will, if well designed, be much more interactive than the book or the lecture. The computer is simply replacing one or more of the learning modes of a traditional course, with the rest of the course structure remaining intact. Courses of this kind are fixed content, fixed order courses, with no learner control, limited in the variety of learning modes and approaches offered to students. Testing occurs infrequently at periods of weeks.

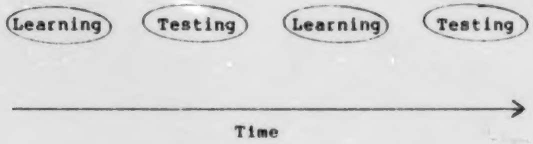
Learning
Testing
Learning
Testing
Time

Figure 2

2. Keller Plan Course with Computer

In this second structure for course organization we see the computer with a course structure popular on a small scale *without* computers. This structure is called the personalized system of instruction, the Keller plan, or the mastery learning approach.

The basic structure of the Keller plan breaks the course down into units, typically requiring about one week of study for an average student. For each unit the course description indicates what the unit covers, what learning resources are available, and perhaps contains a sample test. Students study the unit using available learning resources; the choice of resources may be left to the student, but many courses of this type stress the *book* as the principal learning medium. When ready students take a test covering the unit. The test is graded immediately, and the student receives feedback about difficulties without delay. To continue to the next unit, students must perform almost perfectly on the unit test; otherwise additional study is suggested before another version of the test is given. In some cases additional study is required. Grades are assigned on the basis of competency rather than on a normative or comparison basis.

The course is usually student paced, students having partial or total control over how fast they traverse the material. However, in most Keller plan courses students must face the end of some designated time period (quarter, semester). We can find many variants to this structure, and experts might disagree as to which were "really" Keller plan or PSI courses.

A computer-dependent Keller plan course can use the computer in either one of two ways, or in both. The computer can be used in instructional mode, accessed by students to learn the topics of the unit. Computer material is always available, unlike lectures, allowing the course to be more self-paced. This learning role of the computer is like that in traditionally organized courses; the same material may serve in both, just as the same book may serve both traditional and Keller plan courses.

The other way to use the computer in Keller plan courses is for the *unit tests*. These tests are fundamental in the course, telling both students and instructor when the student has mastered a unit. This testing function can be partially or entirely on computer.

I will not give a full description of computer based testing,[3] but readers should understand that such testing can be very versatile. The problems can be selected from pools of items or, often better, from sophisticated problem generators which produce a widely varying collection of problems of a given type. Tests can be devised so no test is ever given twice under any circumstances.

Immediate feedback on correctness can be offered. We can also provide significant aid to students, aid very much tailored to students' own explicitly manifested problems.

The introductory pre-calculus math course at the University of California, Irvine, developed by Stephen Franklin, uses on-line tests without built-in aid. It assumes that instructors or tutors will provide this aid. On the other hand, the tests in the introductory physics course at Irvine incorporate extensive built-in aid.

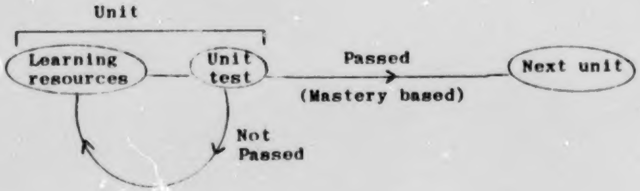

Figure 3 - PSI Structure

3. Test Driven Keller Plan Course

The notion that computer based tests can contain a component of learning as well as testing, suggests a variant in the usual Keller plan format. The notion is to abandon much or all of the preliminary learning material of each unit and focus learning primarily within the tests themselves.

Although teachers commonly tell their students that tests are a learning experience, students seldom believe it. But evaluative studies of our introductory physics course indicate that 80 to 90 percent of the students identify the tests as the major source of learning material of the course. Other learning material may be available, such as a text and lectures, in such a course structure, but the burden of learning has shifted; much of

the learning takes place during testing. One variant of this idea, exploited by Kenneth Bowles at the University of California, San Diego, in his Pascal course, allows students access to the tests as learning sequences before they take them as tests.

With this method we are approaching an organization not possible without the computer. Tests combining learning are practical in large classes only if they are available on the computer. We will see other examples of courses demanding the computer in some, but not all, of the later organizational structures discussed.

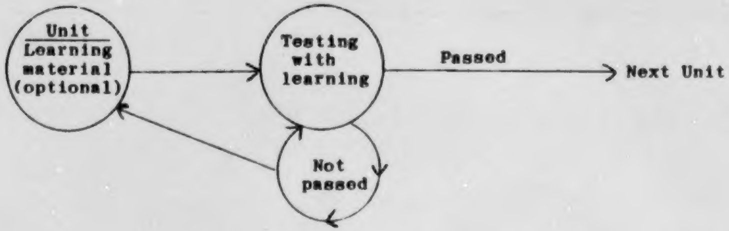

Figure 4 - Test-driven Keller Plan

4. Learning Cycle

Another method of organizing curriculum development, with distinct features going beyond those already discussed, has been proposed by Robert Karplus, University of California, Berkeley. This method is derived from Karplus's study of Jean Piaget's work.

The learning cycle approach emphasizes a notion seldom stressed in conventional courses; an experiential basis is an important component of the learning process. The importance of experience relevant to later learning is recognized with young children, with the use of manipulatables in teaching mathematics, but plays a lesser role in more advanced courses. A typical university course does not even attempt to provide any such experiential basis, notwithstanding this being our best hope for developing students' intuitive grasp of the subject area. Developing students' insight is just as important as developing ability to do the essential tasks.

Karplus' concept of the learning cycle involves three components, the first being the experiential component, the second a more formal learning component. The aim of the third component is to see whether students can use what they have learned.

Computers can play a role in all or some of these activities. Thus, in many disciplines computers can furnish, by means of computer simulations, the experiential first component of Karplus' learning cycle. These computer based simulations provide students a variety of experiences, either simulating phenomena in the real world or creating phenomena that could never be found in the world. Within the Educational Technology Center we call such activities "controllable worlds." The term "micro worlds" is also used. For example, for the beginning physics course at Irvine, mentioned here, we have available an $F = ma$ Newtonian world; students can "throw" bodies and watch how they behave under the action of various force laws. All aspects of initial conditions, force laws, constants in the force laws, scale of plotting, what variables are plotted, or combinations of variables, are completely under students' control.[4]

Computers can also function in other components of learning. The entire learning cycle can be computer based, for each unit of a course. As an example, we could consider materials developed at the Educational Technology Center which follow such an organizational scheme. One project concerned public understanding of science, stressing the nature of a theory, how theories are discovered, and related items. Another project focused upon helping students to reason formally, in the Piaget sense. Each product has an organizational structure similar to the learning cycle, beginning with an experiential basis. The various modules developed in these projects are discussed in fuller detail in the literature.[5]

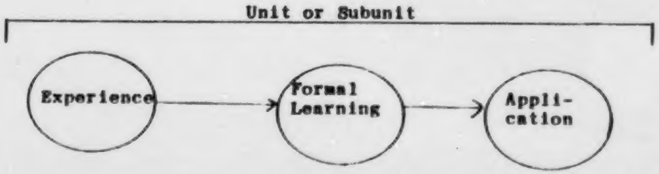

Figure 5 - The Learning Cycle

5. Complete Mastery Learning Cycle

The organizational scheme suggested in this section combines the features of the last three schemes mentioned. It employs something akin to Karplus' learning cycle, particularly with its emphasis on the experiential basis. It also incorporates the mastery learning ideas of PSI or Keller plan courses, requiring students to learn a topic almost perfectly before leaving the material. The computer is suitable for all parts. Self-pacing is typical, and it is easy to allow alternate contents. Again, the type of organizational structure that would be possible, with computer simulation and mastery based testing, would only be possible with computer modes of organizing courses.

Recently the armed forces have discussed a mode of course organization called functional context training, which starts with the application, perhaps simulated on the computer and then shifts into learning sequences, depending on students' difficulties in the application. This procedure closely relates to the complete mastery learning cycle, particularly if the initial activities are simulated on the computer.

Very few courses follow the compete mastery learning cycle. But the promise of such courses is considerable. This approach deserves extensive further study.

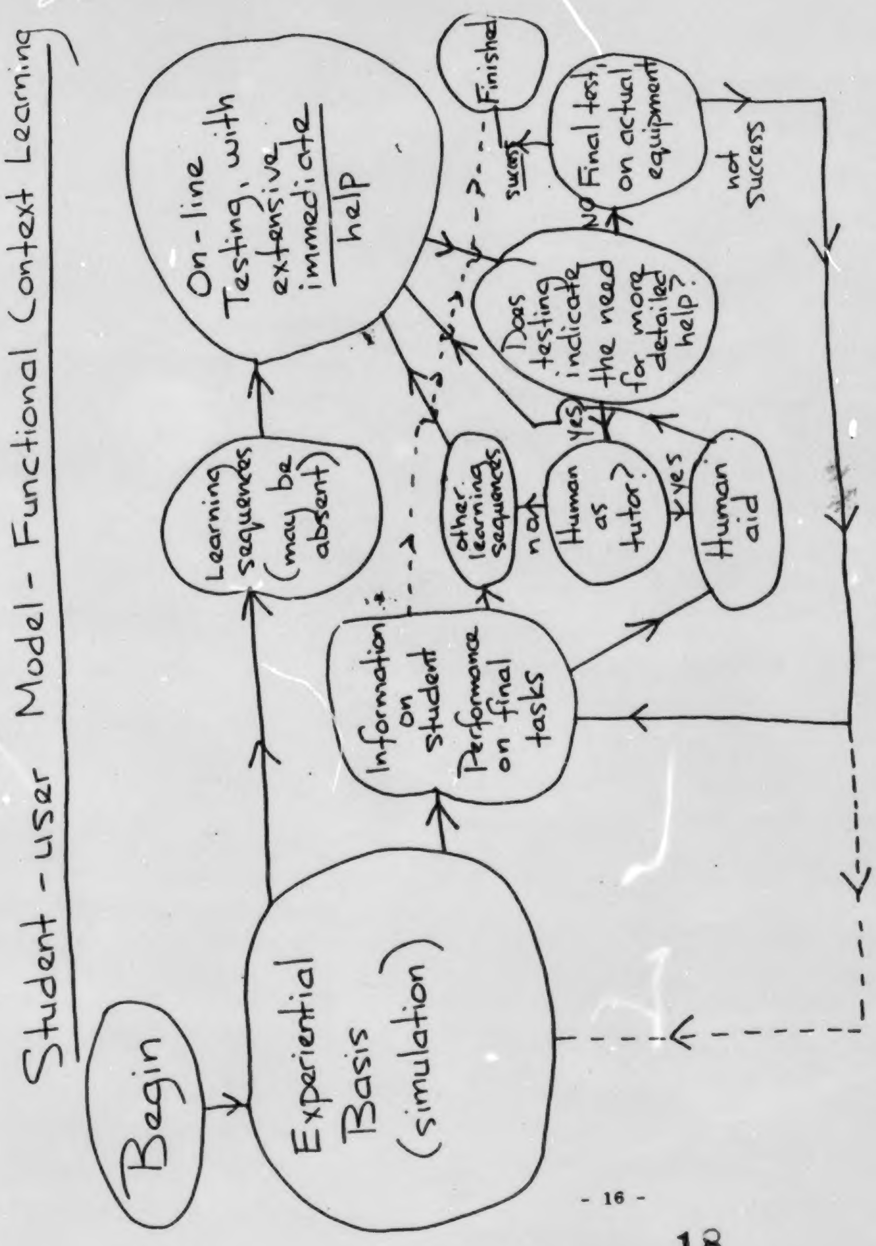
Student - user Model - Functional Context Learning
Begin
Experiential Basis (simulation)
Learning sequences (may be absent)
On-line Testing, with extensive immediate help
Information on student Performance on final tasks
other learning sequences
Does testing indicate the need for more detailed help?
yes
Human as tutor?
no
yes
Human aid
Final test, on actual equipment
NO
success
Finished
not success

Figure 6

6. Student Organized Courses

This possibility, already suggested in connection with use of LOGO, provides students a very effective set of tools on computers for the learning process, including simulations and languages. Students are allowed virtually complete, or mostly complete, choice as to which of these tools they use and how they use them. The instructors impose no ordering on the course, at least in the ideal sense. Students will presumably learn if the environment is sufficiently rich.

As mentioned, it is not clear whether a fully student-organized course has ever been tried in schools, except on a very small scale. I find it difficult to see how lifelong learning experiences could be organized in this fashion; but this approach certainly presents interesting possibilities, for certain areas and for certain students, worth further experimental study.

Concluding Remarks

Undoubtedly courses heavily dependent on computers could be organized in other ways. The suggestions in this paper seem promising and all deserve further exploration. The issue of what is "best" in each situation can only be determined by empirical investigation.

One might raise a further question. In this paper the word "course" appears frequently. But do we need courses? If we think, for example, of typical schools or universities, the existence of courses, particularly in universities, is primarily for the convenience of the registrar or perhaps the instructor,

but not for the convenience of students. With computers we can envision learning as a continuing process, without our current artificial divisions and restrictions.

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Basic Mathematics in Colleges and Universities - Computers as a Solution

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June 2, 1983

Students at every level of education enter with a variety of knowledge derived from previous courses and other modes. Typically universities are very poor in dealing with this situation of heterogeneous background. Furthermore, just looking at transcripts offers no clues. Mathematics books are particularly important because both math and science courses depend on them. Many universities require examinations for entrance into such courses as calculus and have courses prepared for students below that level. The problems of students are seldom those that can be handled well in a "whole remedial course" procedure. Each student has unique needs depending on that student's background. While in universities we give lip service to treating students individually, very little of this happens in our classes.

As a result, during the past few years we have had "inner universities" arise within many universities. This inner university is called a "learning resource center" or some similar name. It is a court of last refuge for students in trouble in their courses. The existence of learning resource centers is a strong condemnation of our traditional courses. If we were doing our job fully, such centers need not exist.

I will argue that a clear way of dealing with this situation exists which, if carried out nationally, could solve the problem almost simultaneously and at a reasonable cost through the entire country. I refer to the development of flexible, highly interactive, graphic computer based learning modules to cover these areas of basic math. This material would be used by students strictly on their own, or it could be available in learning resource centers.

In those universities moving toward requiring all students to have certain computers, such as Carnegie-Mellon University, it would naturally run on those computers. We would expect it to be available on a range of common computers, those coming into use in schools at present. No credit or course type structure is needed with this material, as the units would be directly usable by all students. Some conventionally organized universities would use them within courses too. The emphasis would be on mastery learning, demonstrating conclusively that the student fully knows each of the mathematical tasks involved.

The basic format of these materials would be a series of problems, covering the entire range from simple arithmetic through algebra and trigonometry. The problems would all be presented at the computer. Each problem would arise out of a computer based problem generator, so an infinite number of similar problems would be available to students. Some immediate assistance would be available to students in connection with each problem; this assistance would be highly interactive computer aid, not just verbal information which the student reads passively. Assistance would also be available on a broader scale for students who are having severe problems with certain identifiable types of problems. Students would then be recycled through the problems, with additional aid if necessary, until they can perform at a mastery level on each type of problem.

Note that in material of this kind students move very quickly over anything they know, and so all student effort is focused on exactly the material they need help with. So student time is used in an effecient manner. The materials would also be flexible; particular problems could be taken out of the pool or other changes made in the way the exams run to suit individual circumstances.

The materials would follow the best strategies available for producing modern computer based learning materials.[1] Extremely competent teachers from all over the country would be involved in the pedagogical design sessions to structure the material. Additional information about production strategies is available from the Educational Technology Center.[2]

Costs

Although no careful cost estimates have been made, comparisons of this project with other efforts at producing very high quality learning material on the computer would suggest a budget of about $350,000; two to three years would be required. It is expensive to produce good curriculum material, independent of the medium. We could not expect these materials to be produced by one teacher in that teacher's spare time.

Whether we regard these costs as considerable or as small

depends on the scale being considered. That is, if the materials were used in only one or two universities, the cost would be great. If the materials were available throughout the entire United States or even in other countries, then the cost would be small on a per school basis.

A number of possibilities for funding can be suggested.

1. Federal Grant

The simplest way to fund a project of this kind would be through a federal grant.

2. Commercial Support

A second possibility would be support from a commercial publisher or computer vendor, with the idea of marketing the material.

3. University Consortium

A third possibility would be a group of universities working together, each contributing some funds to the total project. These universities presumably would then have free use of the material, except for duplication costs, and they could market it to other institutions. They might well make a profit eventually.

4. Combination Funding

Although it complicates funding possibilities, funding might come through some combination of the above sources.

Final Comment

Adequate material of this kind could solve the problem for most universities in the United States, providing an extremely flexible way of meeting the needs of students and one which conserves valuable student time. I frankly see no other possibility.

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NONTRIVIAL, NONINTELLIGENT, COMPUTER BASED LEARNING

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Technical Area that will best fit the paper: Computers in Everyday Life

Neither this paper nor any version close to it has been or is being offered elsewhere for publication, and, if accepted, the paper will be personally presented at the 9th World Computer Congress by the author or one of the co-authors.

Signed______________________________________

October 25, 1982

Abstract

Computer based learning materials vary widely in their apparent "intelligence." At one extreme, many programs currently being sold for the educational market are extraordinarily limited (and unnecessarily so, we contend) in their ability to respond to natural, open-ended user input. At the other extreme, there has been much discussion recently about so-called "intelligent tutors" that use techniques from artificial intelligence, but at a considerably graeter cost in terms of hardware requirements. This paper uses three examples of learning materials for personal computers, produced with careful attention to pedagogical design, that appear to be "intelligent" but which have been implemented on small machines and with a minimum amount of software overhead.

The past few years have seen increasing interest in and use of the computer as a learning device in a variety of areas where the computer is *not* the subject matter of the area. Thus, we see it being used to aid in learning elementary arithmetic, college physics, and in many other disciplines. Indications are that the computer's presence in the educational situation will continue to grow. The sudden emergence of a dozen or so magazines particularly concerned with computers in education and the entry of at least a dozen publishers (both older, conventional, book publishers and new companies) into this market are indications that the movement has gained momentum.

Unfortunately the quality of many of the commercially available computer based learning units, leaves much to be desired. Many of the examples (commonly available) do not reflect the best usage of the computer.

This situation may give some individuals the impression that computer based learning material always deals with trivial or unimportant learning activities. The existing commercial examples have tended to reinforce this notion. Another point of view is that existing examples indicate that computer based learning is still extremely poor, but that a future type of activity, often called "intelligent computer based learning," will lead to better material. The claim is that intelligent material, generated by the techniques developed in artificial intelligence, will be required to get away from the trivia.

My intent is to argue through examples that this is not the case. That is, we will argue that we already know how to produce good computer based learning material; indeed, we will point to many examples of material which are, we think, effective learning materials. This is not to say that we cannot improve through the use of Artificial Intelligence or a variety of other techniques. Rather, it is to say that it is a gross oversimplification to claim that we have not developed good material without these techniques.

The principal aim of this paper is to contribute an understanding of how the computer can be effectively used in education. There is already ample evidence to show that the computer can be effective in a variety of situations.

The three examples we will use show a variety of strategies in education. They come from work done at the Educational Technology Center at the University of California, Irvine. We have been involved in the development of computer based learning materials at Irvine for fourteen years and have developed in many areas and at many levels. The three examples are by no means our total output but were chosen to show our range.

The implications extend far beyond education. People in many areas besides learning desire interactive computer based material that is friendly to use. For example, the entire office systems field could profit greatly using many of the tactics used here, both in introducing people to the new environment and in coaching them through the new environment. Many applications of the computer involving novices could also use the types of techniques which have been used in good computer based learning material. For example, it is often necessary for people with little computer experience to access data bases. Yet many data bases are currently designed in a way that makes this access extremely difficult. The bibliographic data bases, for example, were initially touted as being usable by the casual user; however, most of the bibliographic data bases are in fact used by trained librarians.

Example 1 - Physics Quizzes

The first set of material to be discussed was developed in connection with an introductory physics course at the University of California, Irvine. This course has been taught for approximately eight years in an increasingly routine fashion.

The basic pedagogical problem was to provide individualized aid and assistance to the many students who take a large, beginning science course. The computer has proven to be an effctive and popular medium for achieving this. One variant of the coures has used the computer to provide such aid. In recent years in which this course was taught, with the computer as an option, about 400 students chose the computer variant; less than half this number chose the noncomputer variant. In universities large numbers of students learn through lectures and textbooks in an environment which provides extremely little individualized aid.

A second goal was that all students learn everything well. That is, we did not want to create the type of course where some students learn the material well, but many students, perhaps the majority, end with only a very partial view of beginning physics. This type of course is often called a mastery course, because the requirement is that every student master the material. This is not to say that people will not leave the course for one reason or another; our hope was to reduce the number of dropouts over

the standard course.This course, which has been well described in the literature,[1] will only be described briefly here. The course is divided into a series of units, similar to the system used in the Personalized System of Instruction or Keller Plan strategy. For each unit several on-line tests are available. Students must do almost perfectly on these tests before being allowed to proceed to the next unit. Typically the student will take a given test a number of times. The tests are not only tests; rather, they provide large amounts of learning material. Often this learning material is highly specialized to the precise student needs. That is, if a student works a problem, the type of help given to the student who does not succeed may reflect the specific difficulty the student was having. Although this material is described as quizzes, there is a constant flow back and forth between the quizzing and the learning activities in the material. We should comment, incidentally, we never use such undesirable techniques as multiple choice within these quizzes. The student completes the course by completing the units in the course. There is a separate written final exam.

In order to give a better understanding of what is involved, we will describe one of the 27 on-line quizzes, a quiz called SLOPE. This quiz is taken early in the conventional course. (Students have a choice of two different courses, to allow student choice of content.) SLOPE will normally be seen by the student in the first week of the course. It is of moderate difficulty. From a content point of view it might be described as geometrical calculus, but in the context of the physical concepts of position, velocity, and acceleration, the aim is that students given curves of one of these versus time should be able to identify and construct correct curves of the other two. Thus, differentiation and integration are involved, but with graphs rather than with functions.

SLOPE begins, as do many of the quizzes, by asking students if they would like to have a help sequence for the material. The help sequence does not count as part of the 40 minutes that students are given to complete this and the other quizzes. A help sequence is an interactive computer based learning sequence going over the concepts of the quiz. Within the help sequence, very different from the quiz itself, students proceed to construct a velocity-time curve, point by point, from a position-time curve. Remember that it is the student's option to use this help sequence.

The first step in the quiz consists of several questions which check on the student's knowledge of how to read graphs. While we could expect most of our beginning students to be able to do this with no difficulty, it is important in the early stages of a physics course to identify students who are lacking such critical skills. The first question, for example, presents a curve (a different curve each time the program is run) and asks the student what the position is at a randomly selected time. Note that in effect we have an infinite variety of questions of this kind, and that therefore no students ever receive an identical question.

In the second stage we try to find out whether students can identify points where the velocity is 0 from a position-time curve. The internal pointing device in the system is used for

this purpose. Again, the help is very selective. Instructors will often know what the common student difficulties are, and so these can be anticipated within the quiz. For example, on this problem the most common difficulty is that students will point to places on the curve where the position rather than the velocity is 0. In this case it is easy to give very responsive and helpful feedback, as we do.

The main body of SLOPE has three parts. First, the student must be able to identify a correct velocity-time curve, given a position-time curve. This is repeated for an acceleration-time curve, given a velocity-time curve. Finally, in the last part the student is given a velocity-time curve and is asked for numerical information about position at certain times. Again, in all these cases random choices are made, so the questions are different each time the quiz is run.

We remind you that SLOPE is only one of twenty-seven quizzes. These quizzes were developed many years ago in a timesharing environment. Currently we are beginning the process of moving sixteen of these quizzes to personal computers, where they will be marketed by a major textbook publisher.

Example 2 - A Controllable World

The second example presented here is also intended for the first part of a beginning physics course. The pedagogical purposes, and therefore the computer strategies followed, are entirely different. The issue here is an important one in any teaching area. It is relatively easy to teach the techniques, and even to teach people how to solve particular kinds of problems. But the development of insight and intuition into difficult subject matter areas is very difficult to teach students, and so is frequently ignored.

The program described is intended to build intuition in beginning physics, where students are looking at systems involving moving bodies. The interesting issues are the forces involved, the parameters in the forces, and the initial conditions. Programs of this kind are possible in a variety of areas. We call them controllable worlds. They have also been referred to as microworlds by the computer education group at the Massachusetts Institute of Technology. In any case the notion is to provide just those capabilities by means of a facility which allows the student to play with the phenomena involved, to gather experience through either a free play arrangement or, better with large classes, a play arrangement where some guidance is provided.

A particular program was first developed in a timesharing environment. Then another variant was developed several years ago in a personal computer environment. The two programs are by no means identical. Each had some capabilities not available to the other, but they each had the same basic capabilities. They were both very easy for the novice student to use and had a great deal of instructional material on how to use the program built into the program. Therefore, it was not necessary to "teach" people how to use the material. A wide variety of responses was accepted. If one wanted to draw a graph, one could say draw, graph, or plot, for example, and the arguments could be given in various ways too, such as "x, y", or "vx vs. x." The student can plot any two or three meaningful physical variables. Indeed, in the personal computer version the things to be plotted can be any algebraic combination of any of the variables. The student also has control over the initial conditions, the parameters in the force laws, and on what force law is used. All these, however, are not required initially--when the student first picks a force law the program is immediately in a position to plot something.

In a relatively brief time the student can acquire many experiences relative to moving objects, can vary parameters to see what happens to the graphs. Students are not restricted to looking at the motion of the objects, but can also plot the various abstract spaces which give insight into the behavior of physical systems.

When they were first developed these programs had some severe problems in actual usage. While highly motivated students in class would use them eagerly and enjoy them just as the professionals did, many students were not successful. We overcame this problem by developing a set of workbook materials which guide students into the critical cases and which control, to a certain extent, the discovery process. The student was always free to go off on his or her own if that interested them.

We expect the personal computer version of this program, with the associated workbook materials, to be available soon through CONDUIT.

Example 3 - Scientific Literacy

The problem raised by the third example is an entirely different one with an entirely different age group. We are interested here in a very wide age group. The programs developed in this project, concerned with public understanding of science, have worked with students as young as nine years old. They have also worked with senior citizens. The programs were developed and tested primarily for public library environments, assuming that anyone who walked into the library, with no computer or subject matter experience, could immediately learn from the programs, without benefit of text materials or teachers.

Note that the problem is again a serious one. Many people in our society have little understanding of the nature of scientific activity. While they sometimes use the vocabulary of science and are, in the political process, often called upon to make decisions which depend on some understanding of science, this understanding is often very weak. Schools do not help in the matter. Most science programs in schools tend to give a quite inaccurate view of how the scientist goes about discovering theories and, indeed, what the theories look like. This is true at the elementary school, at the secondary school, and it is even true at university level science courses. In fact, the topic of the nature of scientific knowledge is such a difficult topic that it is seldom treated in conventional courses. Hence, it seems to us to be an important problem. We felt that the computer could do things that were very rarely being done in our current educational system.

We developed a number of modules in this project, each about one and a half to two hours long for the average student. The basic tactic was to put students in situations where they had to behave something like a scientist behaves. That is, the students gather evidence, form hypotheses, test the hypotheses and change

them, until they arrive at a satisfactory theory. In some cases, as with the one described here, the situations are real. In other cases the situations are imaginary. The environment is a friendly, helpful environment. A student will not flounder forever trying to do something if he or she has difficulties. The environment is a discovery environment in which a student who is making no progress at all will begin to get nudges in the right direction through built-in tutoring, done unobtrusively. Indeed, with all students we try to maintain the feeling of success, the notion that they are succeeding in the learning process.

The particular program we will mention is one that concerns batteries and bulbs. During several hours of the session the student develops a model for simple electrical circuits involving batteries and various light bulbs. The student is not told the critical concept as is usually the case in the typical classroom presentation. Rather, the concepts are discovered in a fashion just described that is quite consistent with the way a scientist might go about investigating such a problem.

The reader who is familiar with some of the curriculum development projects in the United States in the 1960's will recognize the batteries and bulbs materials described, because similar units were developed in a number of the elementary science curriculum projects. But the units as developed then, although with interesting ideas similar to the ones expressed here, have not worked in class situations. The problem has been that the units were highly teacher-dependent, and in general teachers are not willing to spend the time and effort to maintain the equipment and to work with individual students in a discovery mode. These materials have been little used despite the large amounts of money which went into them because they do not have a good "impedance" match with the classroom situation. The batteries and bulbs material is, as seen by our testing in the public library environment, independent of teachers and could be used by students all over the country. We are currently beginning discussions about marketing this material with a number of possible vendors.

Conclusions

The three examples presented do not represent the full range of different ways the computer can be used in education. But they do show three different strategies, and in each case they show that the computer even with current tactics can play a very important role in dealing with critical pedagogical problems. In no case are the problems being faced trivial. Indeed, in each case we did not start by asking "How can we use the computer?," but rather we started by saying "How can we help students who have this difficult learning problem?"

We can see both common factors and differences in these programs. First, note that the computer environments run from timesharing through personal computers. More recently our work in the Educational Technology Center has concentrated on personal computers, and we believe that this is the most likely future direction for computer based instructional material.

One thing that is not obvious from the descriptions so far is that all these programs are very graphical. That is, they all use visual information as an important component of the learning process. The notion of developing learning material without the use of visual information does not seem to us to be desirable.

All the programs are highly interactive. When students run them they have the feeling that they are dealing with an intelligent program. But the intelligence does not come from the particular techniques which have been developed in artificial intelligence, but rather from the fact that in each case the programs have been developed by groups of highly experienced teachers. It is the experience of those teachers that is reflected in the program as intelligence, and it is this that leads students to comment that the programs are highly responsive to what they type in and to their individual needs.

Thus, the programs appear to be "intelligent" from the user point of view, in spite of the fact that the computer scientist might not view them in this fashion. The key is the production process which, in early stages, involves small groups of extremely competent teachers and gives these individuals maximum freedom to use insights from their teaching experience. The notion of working in groups is an important one that needs to be stressed here; we find that no one individual can produce this material as effectively as a group can. The production process has been described fully in literature available from the Educational Technology Center. We believe that it is one of the key ideas to future computer based learning material.

It should be noted that all three of these programs try to exploit the medium of the computer as fully as possible, not necessarily bringing in other learning media. This is undoubtedly realized most successfully in the scientific literacy material, which normally runs in situations in which no teachers and no print material and no films are available. This is true to a lesser extent with the physics quizzes. With the controllable world programs, as indicated, we have found that the print material is useful, but there are tactics where it can be avoided here too. Projects which depend on extremely complex mixtures of learning media seem to me to lead to problems in typical classroom environments.

Finally, we wish to make it clear that we am not arguing against the use of artificial intelligence in computer based learning material. Indeed, we think that those techniques will also be extremely valuable in improving the quality of learning material. But we think that what is needed is some combination and hybrid of the best aspects of contemporary computer based learning and the best future possibilities that may come from built-in intelligence. Again, it is not an either/or question and phrasing it in that fashion creates an artificial dilemma. The issues we need to deal with are learning issues; the problems we need to deal with are the important learning problems. All computer techniques that contribute to this should be used.

Reference

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A preliminary taxonomy of ways of displaying text on screens

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This paper considers the computer screen as a space-time arena. It develops a taxonomy of the various variables associated with the display of textual material.

Introduction

More and more people are seeing text material displayed on screens through both video and computers. For example, text-based displays are often used for reference, perhaps interactively, as with reservation clerks at travel agencies or airlines, who use such displays for many hours each day. Similarly, in a computer-based learning situation the student may use a screen for an interactive program or in the near future as a surrogate book, particularly as the cost of delivering textual material via computer or video technology declines as compared to the cost of delivering it on paper. The question of *how* text will be displayed on the screens will become particularly important as videodisc technology and computer technology are combined.

In spite of this increased use of screens for displaying texts, the vast majority of screen displays are probably far less effective than they could be. The issues involved include *legibility*, *memorability*, and *motivation*. Increasing a display's effectiveness is not just a matter of improving the screen's resolution or changing from monochrome to color; ideally, we would also take account of users' reading purposes and draw upon the skills of information designers in deciding how information should be presented. We could then see the possibility of aiding and improving the reading process, as in *interactive* reading, a new reading style possible only with the new media. At present, we are rather far from this. Often, the way text appears on a screen is almost an accident, determined either by the programming languages involved, by the computer hardware, or by limiting users' control to matters that have nothing to do with the visual appearance of text. This is perhaps excusable, since little is available in the literature as yet in the way of good, empirical evidence on *how* to display text on a screen; further, there is a scarcity of information designers with experience of the new media, so there is a danger that designers may rely on experience with older media, such as print, and carry over inappropriate solutions.

In our view, all those who work with new media are in urgent need of an appropriate classification scheme. The body of this paper presents a preliminary attempt to draw up such a scheme, in the form of a taxonomy of the various types of textual treatment which are now possible in the computer environment. This may provide a better basis than is currently available for the information designer who has to compare and choose between various presentational options.

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Display medium versus print material

Many information providers treat the screen as if it were the page of a book. This is not surprising as the book and related print forms are the dominant reading modes now. Yet even a cursory examination of the display screen and reflection about the possibilities indicates that many differences exist.

The *quality* of text possible on most CRT screens is much poorer than the quality of text available in print materials. Letters formed from a limited dot matrix are at best crude. Hence, legibility is likely to be an even more important issue on the screen than it is in print.

The possibility of the control of the time domain is another striking difference between screen and print. Many different time considerations are possible. In this regard the screen has a closer affinity to a film than a book.

Furthermore, the economics of the two situations are very different. One of the most striking differences comes with the question of blank space. *In books space costs money*, since the cost of printing books is roughly a linear function of the number of pages in the book. However, on the computer screen blank space is *free*. Hence, size for size, blank space can be used in a much freer fashion in computer displays than it can be in the equivalently-sized printed medium.

I do not wish to imply that all the previous work done with text display in *printed* form is useless for understanding what happens on the screen. In fact, much of the material concerning legibility and readability appears to be directly applicable. But without further work we cannot know if this information extends to the screen. And, as indicated, there are many differences between print and screen.

The classification scheme

The purpose of this present paper is *not* to describe experimental work showing how the screen should be used. Rather, it is a preliminary attempt leading in that direction, an attempt at developing a taxonomy of the various types of textual treatment which are already possible in the computer environment. Below, I consider both spatial and temporal factors.

The reader should realize that many of the factors discussed could be controlled either by the *designer* or the *user*. Thus, the user might adjust timing delays to suit individual preferences. The issue of which factors *should* be turned over to the user is one of the most interesting and most important topics for exploration. Further, the question of *how* the user is to exert this control is also critical. Both of these may be dependent, as with many of the other factors discussed, on the *type* of use.

The taxonomy presented may not be complete. Nor is current usage of these terms always unambiguous. This paper sets down possibilities with the hope that readers will suggest others I have missed. Once a reasonable taxonomy has developed we can study through appropriate experiments the effects of these different factors in particular situations such as student learning.

For convenience I have grouped the various factors in categories.

1. The time domain

One of the most critical differences between printed material and material displayed by the computer is that the computer can control *timing*. Thus, in a sense the computer is more like a film display of text or a television display of text than it is like a book. Being able to control timing may enable us to emphasize certain material (words, phrases, sentences, sections), to show structure, or to increase interactivity. Several timing factors need to be considered.

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1. Overall rate of text output. In most existing systems text is delivered to the screen at the fastest possible rate, the channel capacity. In communication-based systems (typically timesharing systems) it is difficult to do much about this; the channel capacity or, in computer jargon, baud rate, determines the output rate. But stand-alone (single user) systems allow us to choose our display rate, and to vary the time delay between two characters. Thus, the 'image' can appear instantly or at some slower rate. The rate can be controllable by the user. The relationship of this rate to reading speed may depend on how the text is added to: one complete line at a time or one character at a time, for example (see section VII).

Of particular interest is how readability is affected by the speed of output and also how attitudinal factors depend on this. My speculation would be that a large amount of text displayed very rapidly would create a negative impression, but this is only a conjecture.

2. Relative rate of text output. In addition to the 'general' slowing of the display rate just discussed, special delays might apply to particular parts of a document for emphasis. So we could pause both before a key word and after it to give it a particular emphasis. The delays might be of different lengths. Or we could impose uniform delays after *each* word. A similar approach could help to emphasize phrases or even sentences that need special attention within material.

3. End of line delays. If lines are revealed progressively, at a fast rate, it may be desirable to have delays at the ends of lines to allow for eye movement to the next line.

4. Delays between writing on different parts of the screen. Pauses may help between writing some material on one part of the screen and then writing some other materials elsewhere on the screen.

5. Delays between text and graphics. Although our major concern is with text, it may be that the text is interwoven with graphic material. Perhaps a few words will appear, then something graphic will happen, then a few other words, then something graphic. This resembles what goes on at a blackboard while the instructor is both talking and drawing. In this situation a possible approach is to delay during the transition from text to graphics and the transition between graphics and text, again allowing a shift in the viewer's attention.

II. Word-phrase emphasis

As already stated in connection with timing, it is often desirable to emphasize particular words or phrases. A variety of other visual tactics which come under the general rubric of types of display are possible. These physical methods of emphasis could be important in aiding reading. Fonts, discussed later, also can provide such emphasis.

1. Flashing. By flashing we mean that a particular word or a particular phrase appears brighter on the screen for a period of time. This might be done on some type of displays by overwriting and other types of displays by rapid switching back and forth between bold and nonbold type fonts.

2. Blinking. A variant of the above is that a part of the text can blink off and on. The *rate* of blinking is a variable.

3. Reverse video. A critical part of the text might be, for emphasis, in black on white rather than in the usual form.

4. Bold. Words or phrases may be in bold. This is discussed further later.

5. Text movement. Some display systems will allow an individual word within a sentence or some other larger grammatical structure to move around on the screen independent of the rest of the text. Thus, the material might oscillate. This text animation then would also serve as a way of emphasizing the material.

6. Color. Another variant in this direction is the use of variable colors such as using different colors for different grammatical categories of words in a sentence. (If color is available, sound may be as well. Although difficult to incorporate in a textual taxonomy, the use of sound can also, in a variety of ways, emphasize words, phrases, or other material. This might be just the ringing of a bell or it could be a much more extensive use. Thus, we could use musical background just as in a film.)

7. Underlining. Underlining is a traditional way of emphasizing words and phrases in typed material. Underlines can *flash* and *blink* also.

8. Word-phrase spacing. Material can be emphasized by displaying it with more than normal spacing, either horizontal or vertical.

III. Lines of text

In one sense the basic unit of text display on most screens is the line. In a book the line is the same for all users, but with a screen it can vary with users.

1. Length of line. Some evidence with regard to traditional media suggests that longer lines are difficult to read. Thus, an interesting factor to investigate is the effect of line length. As with many of these items we can let the user pick line lengths.

2. Natural breaks. Often, the positions of 'carriage returns' or line-endings are determined by the overall consideration of page or screen width. Another strategy is to have the line breaks at the ends of *natural* phrases, perhaps combining this with a maximum line length.

3. Hyphenation. Evidence indicates that hyphenation hurts readability in printed material. Nevertheless, hyphenation is very widely used in electronic media also.

4. Justification. Lines of text can be arranged in a number of ways. The most common is the typewriter-like situation where the lines start always at the same point at the left-hand margin, left justification. Often seen in books (but not necessarily helpful in reading) is justification at *both* the left and the right ends of the line by insertion of spacing in the line. This can be done on display screens too, but often the only variable space allowed is that associated with the *spaces* between words; that is, the spacing between *letters* cannot be varied. Furthermore, even word spacing is controllable often at a rather crude level, a full space. Justification in conventionally printed material involves much more flexible control of space; the technique of 'letter spacing' adds small spaces between all the letters.

A third possibility is to justify only the right margin, letting the left margin be 'ragged'. The fourth possibility is to center the line within the space allocated for it, so that neither the left nor the right margin is justified. A variant of this is to put random amounts of space at the two ends; we might consider this a fifth possibility: random justification.

5. Number of columns. Both one and two column formats are employed in books, sometimes even more. These possibilities also exist for the screen.

IV. Space

A screen contains *both* text and blank space. Although it is perhaps straining a point to put it into this category, I will include such issues as the overall text density on the screen in this discussion of space.

1. Text density. This might be defined most simply as the ratio of the screen area occupied with text to the total screen area. Perhaps in making this computation we should include the space at the ends of the lines that would be needed for justification, since that is not typically available for other use.

An important item, difficult to quantify, is *where* the blank space occurs. For example, we may have blocks of text expressing different ideas; the differences can be emphasized if the blocks are separated and placed on different parts of the screen. The question there is whether the blank space can be simply *randomly* determined perhaps by the machine itself, or whether it should be determined by a competent graphic *designer*. One might call this the issue of statistical blank space versus controlled blank space. Control could be thought of as referring either to the placement of the material or to the blank space.

2. Space between letters. Normally, letters are not written directly next to each other; some amount of intervening space is left, usually small. The space between letters is an interesting variable to investigate in connection with the present problems. It might also be described as the size of the letters in relation to the space in which they are put, and so could be indicated by the same type of ratio expression indicated in (1) above.

3. Space between lines. Another specific consideration is space between lines of text.

V. Characters

1. Comparative character size. Letters can themselves be of different size. Many current screens allow only a single size letter or only a few static sizes, but the possibility of variable size letters is not hard to imagine and is already possible with some systems. An additional possibility is the mixing of letters or various sizes in the same presentation, perhaps for word-phrase emphasis or for other reasons.

2. Fonts. In print media a variety of fonts will be used. Thus, a heading font may differ not only in size from the body font, but may be a bold or italic variant or a different type face, perhaps for emphasis. The font can be a conscious choice, but this is rare on today's screens.

3. Character aspect ratio. The same font of characters can be displayed with varying aspect ratios, the ratio of a letter length to its height.

4. Quality of characters. Most computer displays still have very primitive, almost barbaric, characters. These characters are often made up of very limited dot matrix formats. But some displays, such as the Xerox Star system, allow better type fonts.

VI. Page aspect

The traditional printed page was higher than it was wide, with a variety of ratios. CRT screens also show a variety of ratios, but except for a few word processing systems the tendency is to make the width the larger dimension. Many of these screens are TV-based having the aspect ratio of 3 to 4. Some systems have a square screen. Although this factor may not be important in our consideration, it would be desirable to determine that through actual usage rather than speculation.

VII. Overflow handling

Eventually as text is displayed on the screen, either the entire screen or the 'window' or viewpoint in which the current material is being written will be full. The points raised in this section have to do with the action taken under these circumstances.

1. Scrolling. Most of the common, inexpensive displays use a simple scrolling mechanism. That is, when the user gets to the bottom of the screen every line jumps up by one line, and the new line is

displayed at the bottom. Thus in this circumstance (if the screen is not cleared) most of the time associated with any long text output will be spent reading the bottom line, which may appear 'instantly', character by character or word by word.

A useful variant under many circumstances is to allow scrolling of more than one line at a time; the number of lines scrolled can be chosen either by the program designer or by the user. Another variant is that scrolling can either occur automatically, or it can occur after the user is queried as to whether scrolling *should* take place.

Scrolling can be a property of the full screen. But we can also scroll individual areas of the screen. Thus, some material can remain on the screen while other material is scrolled. Several textports (areas of the screen) can be manipulated separately.

An alternative to scrolling is a complete clearing of the screen, with text written at the top of the screen once more. Again, this can be done optionally with the user requesting it, or it can be done automatically when the end of the page is reached, possibly combined with some suitable delays as indicated in the section above.

A special case of scrolling might involve only a single line of text. The material thus is constantly being erased and rewritten.

2. Panning. In scrolling the lines always move by an integral number of lines, typically one as indicated. In panning (or 'smooth scrolling') the text moves upward or downward at some steady rate. As with other items considered the rate can be chosen by the designer or can be under the control of the user.

3. Crawling. A small amount of overflow can be handled by having the entire text move to the left, as in some news signs on buildings.

VIII. Aids to browsing

Books are seldom read completely linearly. Some books are almost never read in this fashion! The typical situation for browsing or searching might be where the reader wants to find a particular piece of information or wants to obtain a general impression as to what a book is all about. I use browsing to include both of these categories, although they might be split or perhaps better terms might be developed. Convenient browsing is a very important property.

1. Indexing. Most books, and much other printed material, contain indices. They vary greatly in completeness. An index can also indicate the degree of importance of a particular reference, the level of treatment, etc. Indexes can be selectively displayed on the screen.

2. Free-form indexing. An alternative to an index is the ability to search for *any* word or phrase, possible in a computer environment.

3. Page flipping. Page flipping is the facility to be able to move either forward or backward rapidly in gulps of pages at a time. The rate can be selected by the user. In a variant on page flipping, on each page key words or phrases (perhaps user-selected) can be highlighted by one of the processes discussed above in word-phrase treatment.

4. Hypertext. Hypertext is a word invented, I believe, by Ted Nelson. The notion is to allow a type of super browsing capability, where the *depth* of browsing can be controlled from everything to a very brief summary of the material to the full text material. An intermediate stage might offer a summary of each page or each group of pages, so that one could decide whether that was the page at which the material was likely to be usable. The user must be provided with some easy way of controlling this situation. I should hasten to say that the word 'hypertext' also includes other concepts besides this, ones that are not directly relevant to our present interests.

IX. Marginalia and cross-referencing

Notes in the margin, and other similar devices, can be very useful. These notes might be 'private', or they might be made available to other readers.

1. *Notes.* A common procedure with printed text is the writing of notes in the margin, a capability also related to hypertext. Although this has seldom been done with textual material displayed directly via computer displays, it represents a possibility. Such notes could be later modified or exanded. (see also section XI.)

2. *Pointers.* The user can also enter pointers from one passage to another.

3. *User highlighting.* A related feature is to allow users to impose their own word-phrase control. This is similar to underlining or using markers in print material.

4. *User editing.* The user may want to change the text for his or her later purposes. Implementation of such a facility will also have to consider privacy factors. The user should be able to state whether a particular note or pointer is to be readable by other users of the same text (if that is possible on the system), or if it is to be restricted in some way.

X. Viewing environment

Displays are often viewed in non-ideal environments. Studies in the area should see how environmental factors such as room illumination, screen contrast, distance from the screen, etc, affect readers. Factors such as the wearing of glasses may be important.

XI. User interaction

So far we have been considering the usual 'reader', a receiver of information. But the computer allows the reader to play an *active* role. In the best case we can have full interaction, as in the best computer-aided learning material. But with little work for us beyond just employing existing print material on the screen, we can occasionally invite the user to type in a *summary*, with the idea understood that such optional input would not be analyzed.

XII. Design of the screen

I mention finally the possibility of special graphic treatments set out by a competent graphic designer as opposed to simply using some (random) combination of the factors indicated.

User control

As we have been noting in our previous discussion, one unique aspect of the computer-driven display as compared in print medium, is that many of the functions which normally are completely determined in advance *can* be turned over to the user. The reader can be provided with many degrees of control which are not available in print medium. Almost all the aspects of screen display discussed so far *can* be under the control of the reader.

But with all these new degrees of freedom come new uncertainties about how to employ them. At least four interrelated issues need to be discussed—the dependence on user characteristics, the question of which variables should be turned over to the user, how user control is to be provided, and the issue of training users in the effective use of this new type of facility.

Different users may have very different needs with regard to the type of control provided. So our characteristics cannot be ignored. One would expect, for example, that a second grade student might best be provided with different types of control over the display than that provided for a good university student or an industrial trainee. Although little research is available as yet, the situation might well be very complex with many different user properties affecting readability and other issues.

In a given situation it might be entirely too complicated from the user viewpoint to turn *all* of the user controllable capability over to the reader. Hence, the issue of which variables should be under user control is one that requires study. At least two issues are important. First, if the user can modify the situation in some particular way, *will* the majority of the users or any users actually use that capability? If something is never used, it should not be given to the reader. But a more important issue is which user controllable variables will actually make a difference to the reader, either in terms of the ease of readability of the material or in terms of affective issues.

The question of how the user is to exercise control is a fundamental one. How is the user to make the decision as to how to do these things, and what is the mechanism by which the decision is conveyed to the computer? These issues are not simple.

At least three overall strategies are possible, and combinations of these could also be followed.

1. Initial choice. When someone first comes to the text or program it is possible to offer the option that they could alter the conditions in some way beyond the 'default' conditions. This would mean that the assumed conditions would need to be told to the user, and then the user could alter these if desired. Some methods for this initial alteration are possible. One is a menu-like approach where one points with the cursor to a line that is to be altered, and then the user is led step by step through the altering procedure.

2. Verbal commands during reading are the next possibilities. It is possible that readers could be entering commands indicating changes. Thus, if readers wanted the entire program to go faster, they might type faster, while the output is appearing on the screen. The advantage of being able to use English is clear. The difficulty is that the user would have to learn something of the vocabulary needed for these changes, although the built-in vocabulary could be quite extensive and therefore flexible. Or this could be allowed only at certain specific places in the material.

3. The third possibility is to allow the user some special mode of interrupting what is happening, to make changes. Thus, a particular key might be reserved for this purpose. When the user presses the key, a menu-like situation similar to that described in (1.) could then ensue, or a query routine could be started.

These possibilities are not intended to be mutually exclusive, but could all be used. Experimental study could determine which ones and what combinations are more desirable. In any case the careful picking of the method of user control could have a profound effect on the issue of readability. It may be, too, that the user may not want to use *any* such control, but would find it easier to stay with the default settings. Again, only carefully done experimental work would determine whether this is the case or not.

The final issue is also a critical one—the process of training the user to use the facility. This interacts with the other factors; a training procedure could be rather simple if only a few alternatives are turned over to the user. The question of the type of user is critical as to what one could provide; less training would be needed for the one-time user than for someone who is going to be reading large amounts of material at the screen.

The training process could involve off-line material in written, slide-tape, or other media; or it could be done directly at the display, using the best techniques of modern computer-based learning. My general preference would be the second possibility.

Implementation comments

It is not difficult to store text in such a form that most of these various options could be picked randomly in experimental situations. Thus, to implement word-phrase emphasis and timing and line length control, we need only to place markers before each word that is to receive special emphasis or perhaps different kinds of markers for different types of emphasis, and similar markers both before and after natural phrases.

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ADVANTAGES OF COMPUTER BASED LEARNING

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Negative views about computer based learning are occasionally encountered. They are held by a number of people, often for odd reasons. This paper attempts to respond to certain negative views, often seen in the literature, by emphasizing positive aspects of the computer as an aid to learning. I will not consider all the "philosophical" objections that have been made. I will discuss a particular example of computer based learning, in the context of earlier efforts, and show how it illustrates the ideas. The example, sponsored by the Fund for the Improvement of Postsecondary Education, was developed in the Educational Technology Center for improving scientific literacy in the general populace.

Some Key Ideas

1. Active Learning. One of the primary goals of many innovative learning projects is that of encouraging active rather than passive learning. Creating an active learning situation is a prime consideration justifying more widespread use of computer based learning.

I have argued in many papers that the computer, working directly with computer based learning modes, furnishes the only possibility in today's mass education for making learning a more active process for millions of learners. Most other learning approaches which are highly interactive do not work when the number of learners grows very large. Indeed, I would even go further than that: It will make learning a more active process!

2. C.A.I.? Many negative writers use the term "CAI" for computer based learning. Although it is a matter of terminology and so not a critical issue, I would like to quibble with that terminology. I don't think it's very useful, and often leads to opposition. First, using sets of initials is abominable and doesn't fit in with reasonable English style. Attending a meeting in an area with which you are not very conversant is usually appalling, listening to people speaking to each other in codes. There is no need to do so. The English language is adequate.

Further, "CAI" is a "red flag" for some individuals. They saw, perhaps many years ago, some material with that identifying tag, and since then they have felt that everything in which the computer is used in an interactive tutorial mode has the same characteristics as whatever they saw.

The net result is that I do not use the initials but speak rather of computer based learning. My emphasis is on learning, what the student does, rather than instruction, which is what someone else does. This emphasizes the notion of active learners, already mentioned.

3. Philosophiscal versus Practical Decisions. I get very worried when people make pedagogical decisions on grounds of

overall philosophy. While it is important to have an overall philosophy in dealing with educational material, we are still at the stage where much is to be learned about the nature of learning. So we must be cautious about making decisions on statements lacking a good empirical basis without considerable practical experience in the area involved.

This has particularly been a problem with the use of the computer in education. Many people have started with strong philosophical positions and have made decisions on how they would use the computer based on these principles. One underlying principle behind such philosophical points of view is that some "right" way exists to use the computer, and that this mode of usage can be justified on the basis of argument rather than experience. This approach is fundamentally anti-scientific. Empirical evidence is essential in making such decisions, particularly in an area such as learning where no fully adequate scientific theories are available.

I would argue that no "right" way of using the computer exists. Of the many different ways possible almost all of them are effective in some pedagogical situation. The decision as to how the computer is to be involved in learning should be made on pedagogical issues, often dependent on the particular area rather than on general philosophical grounds.

5. Experience. Very few of the critics of computer based learning have had very detailed experience with good, modern, contemporary, computer based learning material. I doubt if these

critics have spent many hours during the past several years critically examining such material and making decisions about its use in classroom situations. Thus, I am afraid that the critics are often criticizing entire classes of products with which they have almost no direct experience.

6. Quality of Computer Based Learning Material. The development of computer based learning material is still in its infancy. Use of any new learning mode requires detailed experience and study of how that mode can best be employed as compared with older learning modes.

Many of the people developing computer based learning material are heavily influenced by books and lectures, and so they miss just the component of active learning which is so important. They tend to transpose books and lectures to the screen, and so produce inferior material.

This situation is now changing. As we gain experience, we are producing a wider range of interactive computer material which begins to exploit the capabilities of the medium. Quality is improving. We still have much to learn, and even the best current material will appear rather crude a few years from now.

7. Individualization. In addition to the extremely desirable goal of creating active learners, another advantage of computer based learning deserves close attention. The learner, being active, is often replying to questions from the computer. The computer analyzes each response, and makes further decisions on what learning experiences to present, based on this analysis.

These decisions then can reflect closely the needs of the individual learner, and so the material can be different for each person. We can thus achieve a degree of individualization possible with no other media in environments with large numbers of students.

Furthermore, the time to go through the material can be very different. This is to be contrasted to the typical lecture mode, still the primary mode of teaching (not necessarily learning) almost all courses in our universities and our school system.

8. Quizzes Via Computer. The computer can be used to deliver, grade, and record the results of quizzes. This is one of the most powerful modes of computer based learning. Unfortunately it is often used poorly.

Multiple choice quizzes are an abomination and should never be used in learning situations. Or, perhaps to be a little less radical, multiple choice should be used only rarely in situations where its use simply allows some change of pace from other types of quizzing. In the extensive collection of on-line quizzes developed for our beginning physics course at Irvine we use multiple choice extremely rarely. There is a belief, usually not verbalized, that multiple choice has something to do with computers. It did, as long as one was dealing with mark sense cards and other stone age computer technology. But multiple choice questions need never appear in good computer based quizzing situations.

The most effective aspect of using computer based quizzing as compared to ordinary quizzing is the immediate feedback. This can occur in the obvious fashion of telling the student whether the answer is or is not correct. It can also be much more extensive, offering very detailed help sequences based exactly on the type of difficulty the student has shown in the quiz. The quiz can, in fact, become the dominant learning device in the course as more and more of the learning material is built into the quizzes.

9. Basis of Comparison. One issue that I think must be addressed when one looks at computers in learning is that of the standard of comparison. That is, what other curriculum material, used in what type of environment, is being compared with computer based learning material? Without such a standard of comparison, discussion can quickly become unrealistic. Thus, to compare computer based learning material, or any proposed new mass educational approach, to what goes on when an extremely skilled teacher works with two or three students is unfair and unrealistic. It is more than unfair--given the current problems of American education, such an approach is highly misleading.

To state this in a different fashion, I would not claim that the computer, used in any way in education, will be superior to the extremely good instructor working with only a few students. This very small group learning situation, with excellent teachers, is extremely rare in education at any level. It does occur, for example, in some British universities. Almost every important physicist in England in the second half of the nineteenth century worked with the same tutor. The tutor was unknown as a scientist, but nevertheless the evidence is clear that he was an extremely competent teacher.

I claim that the computer, used in computer based learning modes, could lead (I emphasize could rather than will) to an order of magnitude improvement in what happens in our typical class situation, whether we are looking at the K through 12 system, the university system, or adult education.

Let us take the beginning physics course in universities as an example. What is the typical situation? First, relatively few books dominate the market, beginning with Halliday and Resnick. Furthermore, these few books are extremely similar in both content and problems. In addition to the books a second major learning mode provided in most beginning physics courses is the lecture, typically closely parallel to the text. The book and lecture do not satisfy in any way the criteria of active and individualized learning. The class is often large, but even when the number of students is relatively small, a lecture cannot provide an active learning environment. A few charismatic lecturers may furnish strong motivational impetus, serving as a role model, but that is very unusual, not the common situation.

Many of these courses also require homework, graded, typically rather unevenly, by hordes of advanced students. Feedback is delayed: The time between the moment the person completes a homework problem and the moment when this student gets information from graders, is likely to be days and sometimes longer than a week. Because many people are involved in grading and because there are varying capabilities, the feedback is of highly varying quality. Often the emphasis is simply on assigning a grade, with little "help" provided.

Instructors will have office hours; but if we divide office hours by the number of students in the course, we obtain an extremely small number in the majority of situations. So again little individual attention is available.

I don't want to sound overly pessimistic about the beginning physics course. But when critics say that computers can only teach problem solving the way the developer of the materials wants the problem solved (which may or may not be true), we should look at what happens with learning problem solving in the typical beginning physics course. In looking at computer based learning we must look at the existing classroom situations and at practical ways to improve existing situations to get a reasonable standard of comparison.

Alternatives to typical beginning courses exist. Self-paced, mastery systems, usually called Keller plan or PSI, provide an alternative. Typically these have been successful only with relatively small groups. The Keller plan articles from MIT are very revealing about their difficulties with large physics courses. In developing such a variable-paced course, to overcome the problems of the typical course, we were led to develop our system of on-line quizzes in the self-paced, mastery tradition.

The situation with regard to physics is not unique. I could have discussed almost any subject area. I picked physics because it is the one most familiar to me, and because I have developed extensive material in this area.

10. The Commercial Wave. It is my position that computer based learning material, because of interaction and individualization, can be extremely effective, particularly as compared to any other currently likely possibilities which might lead to better educational systems for large numbers of people.

In another sense, particularly from a long-range point of view, it does not matter in the slightest whether computer based learning material is or isn't better. In either case, we will see more and more of it until it will eventually become the dominant educational delivery system!

The question of whether or not computer based learning material will become widely used is not one that will be decided on rational grounds, based on the effectiveness of the learning situations provided. It is not an "academic" issue. Rather, current great difficulties with education, plus very powerful marketing forces, will be the major factors. These factors will dominate, and the rational issues of effectiveness of this type of learning will not be major considerations. The only question is whether the future of the computer in education will be desirable or undesirable; that issue is still unresolved.

We can see clear signs of rising commercial interest, although I do not have time to look at the issue fully. Almost every major textbook publisher, plus many new companies, are currently gearing up to market computer based learning material. Many computer manufacturers are also moving in this direction. The amounts that these companies are investing are growing rapidly.

We need only look at the textbook market to understand why publishers are moving toward computer based learning, even though there is great uncertainty about the marketing data and marketing strategies. Textbooks are not a growing market, so these companies eagerly seek other markets, while attemping to protect their current market.

I would not want to claim that all the material from these companies is first rate or even reasonable. At the present time much of it is poor. That even poor material can be marketed by major companies is an indication of the need for this material in the schools and universities. The list of existing companies involved is impressive. It includes such companies as Harcourt, Brace, Jovanovich, Harper & Row, John Wiley, McGraw-Hill, Random House, Scott Foresman, Science Research Associates, and many others. The critical point is that the important decisions will increasingly be made by commercial firms, not educators.

An Example - Elementary Science Material

So far the discussion has been theoretical, talking about computer based learning in abstract terms. This worries me for a variety of reasons. We can understand the issues only if we examine actual examples. In this section I consider an example.

Three aspects will be considered: 1) An important pedagogical problem; 2) attempts to solve that problem (which in terms of mass education did not succeed), and 3) a computer based learning variant of these attempts which holds promise of succeeding not only within schools but also in homes.

It would be ideal if I could supply readers access to the computer based learning programs I will describe. It is difficult to convey the notion of a highly interactive graphic learning experience with the passive print medium. But I will do the best I can, hoping that readers can later try the modules.

The educational problem to be considered is important, not only in the United States but all over the world. Present science curricula, particularly as reflected in what the average student learns, do not bring students to an appreciation of the nature of scientific knowledge. Most approaches are vocabulary oriented, presenting words and "facts." These courses convey little understanding of how the scientist goes about arriving at such vocabulary and information. Science is almost presented as a new type of religion; the conclusions must be believed because the scientists say so! Very few students come through the educational system in the United States with any understanding of the nature of science. Yet, in a society heavily influenced by science and technology, such understanding is important. A similar situation exists elsewhere.

The realization that a difficult problem exists and that we are failing to solve it is not recent. Major individuals in

science education have been concerned with scientific literacy for many years. Several thoughtful projects concentrated on this problem in the 1960's. Among these projects were three elementary curriculum efforts that developed materials closely related to the ones to be described, the Elementary Science Study project (ESS), centered at the Massachusetts Institute of Technology, the Science Curriculum Improvement Study (SCIS), in its initial form developed at the University of California, Berkeley, and the AAPT material, A Process Approach. The SCIS project was published in two forms and marketed by two publishers. High school curriculum developers also were conscious of the problem of scientific literacy, as seen in such courses as Project Physics.

In these curricula developments individuals distinguished by their knowledge of science and their pedagogical backgrounds contributed. The SCIS project was important for its pedagogical contributions, independent of the units produced; it introduced the important developmental psychology notions of Piaget to many teachers and researchers in the United States.

The materials produced in these projects were impressive to the professionals. They did focus on the problem of bringing students to understand how the scientist works, how scientific theories were discovered. They used a variety of subject areas; the materials were thoughtfully developed, tested, and improved.

Let me mention one example, the batteries and bulbs unit. Students are given some batteries, some light bulbs, and some wires. As far as possible, the batteries are all similar as are the light bulbs. Students are told that their initial task is to make the bulb light. They experiment with the equipment with this task in mind. Students are not told how to light the bulb; rather they should have the actual experience of a small empirical discovery. In some variations additional help might be given to the student who was slow in finding how to light the bulb.

Lighting the bulb is only the first task. After the student has succeeded in doing this, perhaps in several different ways, the next stage is to verbalize what is necessary to light the bulb, arriving at the notion of a continuous circuit which uses both terminals of the battery and both terminals of the light.

By a series of additional empirical investigations, the students gradually develop a theory or model of what is happening in the circuit. In the course of this investigation such terms as "current" and "resistance" are introduced, although not in the full-scale sense of circuit theory. It is the development of this theory and model, from the empirical basis, that is the focus of the activity. I emphasize that although the student learns something about batteries, bulbs, and electrical circuits in the process, the major focus is on scientific methodology.

What happened when the SCIS, ESS and Process Approach materials were introduced into classrooms all over the country? The results were far less than many of the developers anticipated. Indeed, these units are little used in American schools. These projects were disasters in schools.

Furthermore, examining classes in which the materials are used often reveals little resemblance to what the developers had in mind. The difference between an ideal curriculum, often developed with rosy notions about classes, and the curriculum material in the average class, with the average teacher, is often tremendous. In this instance this proved to be the case. The new materials demanded the active participation of each student. They differed very much from the conventional class situation in which the teacher was often the only active individual.

Any innovative curriculum development has a major problem associated with preparing teachers to handle the new curriculum. This problem had to be faced to make the new elementary science materials usable in every American classroom. Unfortunately, the standard mode is quite inadequate; what happens, almost inevitably, is that courses for teachers are offered either after school or in the summer at local community colleges and universities. These quick in-service courses have long been looked upon as the best way to handle the problem. Even at this time Congress is voting money for this purpose. During the period of the 60's and early 70's the National Science Foundation spent ten times as much money on these teacher training activities as they did on the curriculum developments themselves! Yet this money was, as judged at the time, entirely inadequate for the problem at hand. Bringing classroom teachers in for a few weeks of intensive work was entirely inadequate to change a lifetime of habits and beliefs. For most teachers no such course was available. Even pre-service courses in many teacher training institutions were relatively unaffected by the new curriculum materials.

The teacher training problem in connection with bringing students to understand scientific methodology was indeed difficult. The science background of elementary teachers is very weak. Often the college preparation of elementary teachers was a watered-down physical science survey course, designed particularly for teachers. These courses in almost all cases had little of the feel of what science is all about and were often simply crammed with "facts." So very few teachers had adequate preparation.

Even a teacher who understood the nature of scientific activity often had difficulties in the classroom. The problem was one of time and numbers. Students needed to work individually and to receive individualized aid and attention. In the typical classroom the teacher has too many students and too little time to allow extensive individualized attention for each student. Only a very small amount of individualized attention in all subject areas is possible.

Another unexpected practical problem occurred in classes. The units depended on kits of supplies (batteries, bulbs, wires and other things). When the "second" use of material occurred, components were missing or equipment needed attention. Batteries wear out, light bulbs burn out, things get lost. Keeping the

kits working was a sizable logistic chore; a listing of the "batteries and bulbs" supplies occupied a full page. Teachers became disenchanted with kits, and even schools that had the materials found them unused by the teachers. Again, there were exceptions, but this was the typical situation.

Even if the materials had worked perfectly in classrooms all over the country, within a short time after their development the problem of other people in our society still exists. If one starts at the elementary school, it takes a period of forty to sixty years before "everyone" has the new concepts. The problem of scientific literacy is not only a problem of elementary school but is also a problem throughout our educational system, including adult education.

The net result of millions of dollars for curriculum development and in teacher training was disappointing. The problem of science literacy remained. The excellent curriculum ideas could not be applied to the existing situation in schools. This is not to say that the materials did not work in many cases. Indeed, when a teacher understood the intent and was willing to spend the class time, the materials were very effective. But their total impact on education in the United States has been very small.

Science Literacy via the Computer

Our group at Irvine became interested in this problem several years ago. It seemed an excellent opportunity to use the computer for a major instructional problem, that so far has been intractable using conventional pedagogical strategies. Computer development in this area need not start from ground zero, but could be based on what had already been learned in the existing projects. The advantages of the computer, providing an interactive experience for each user and individualizing the experience to each user, were missing in the typical American classroom when the materials were used in their conventional mode.

For several years we were unsuccessful in finding support. Finally in August 1979 the Fund for the Improvement of Postsecondary Education awarded $200,000 to develop computer based scientific literacy material. We decided, given the emphasis of the Fund, that the major testing environment should be the public library.

The choice of the public library as our major arena for formative evaluation was carefully considered. We wanted our units to work for all students, whether those students had any previous experience with computers or not. We were also interested in future widespread use with home personal computers.

We were very concerned with motivational issues. The library funrishes a good place to determine where the programs "lose" people, lose their attention. When tested in classroom environments, the students are obliged to continue even if the unit no longer excites them. No such pressure exists in a library; a student who loses interest will get up and leave! So simple data gathering could show us where the programs were motivationally weak.

The modules developed in this project have been well described in other literature, so no attempt will be made to describe them fully. As of this writing, they are in final development stage, modifications performed after the testing. Approximately fourteen hours of material concerning scientific literacy are available, assuming an average student user at a display. However, our experience in the public library testing indicates that a given user would often run a program many times, coming back day after day.

One of the units concerned batteries and bulbs, as already described. We were fortunate to work with several people who had great experience in using this material with students at a variety of levels. Among those involved in developing the materials were Arnold Arons (University of Washington) and Francis Collea (California State University, Fullerton). So we were able to benefit from the experience of the earlier curriculum development projects and from the experience of teachers who had used the material extensively.

I have already suggested that the best possibility for batteries and bulbs is for readers to see the material on the computer. For many this is not currently possible. Hence, I describe the unit briefly.

Each of the eight modules occupies about fifteen minutes of an average user's time. The user may move between these modules, and sometimes the program itself will suggest or enforce such movement. The material is highly interactive. A group of users estimated that fifteen seconds elapse between typical student interactions. So this is in no sense a lecture or textbook environment, but rather an interactive environment. As far as possible students are asked to come up with the important ideas. If necessary, they are given partial help so they can still make part of the discovery.

We decided to simulate batteries, bulbs, and wires on the computer. It is not yet clear that this is a wise decision. In another module we do require equipment at the display. But given the difficulty with kits and our desire to have these materials run in schools, libraries, other public places, and homes, it seemed desirable to simulate equipment. We hope that we and others will compare experimentally the advantages and disadvantages of using equipment.

The first module, as with the original unit, has as a goal the lighting of the bulb. The battery and bulb are displayed. The user points to places to attach wires, and they are drawn by the computer. At first the only feedback the student receives is that the bulb lights or not, except that we do point out short circuits. The program keeps an internal record of how the user has been proceeding. If success is not attained in a reasonable time, very specific aid is given by a "tutor" related to the student performance thus far. As with other parts of this program, eventually success is assured for almost every user, although it takes a longer period of time for some than for

others. We follow mastery learning ideas, assuming that everyone will light the bulb through empirical efforts.

The second module is a competency based test to see that students who light the bulb really understand what must be done. If necessary, as demonstrated by the tests, other aid on the formation of simple circuits is given to the student. Students do not view this as testing plus remediation as perhaps an outsider might. Rather, the student sees it as simply part of the process of learning with the computer dialog.

In the third module we start with another empirical investigation, placing various objects within the circuit to see whether or not the bulib lights in each case. After some data is available, the mode switches and students are asked to make predictions about whether the bulb will or will not light. The emphasis on predictions is very strong in the scientific literacy modules. Thus, in the last part of this program many predictions are based on the model of the circuit behavior introduced.

Other modules proceed to develop the model, again based on empirical information. We avoid vocabulary until there is some reason necessitating the use of a term. The terms "current" and "resistance" are introduced in this fashion.

Will batteries and bulbs and other modules we have developed concerning issues of scientific literacy solve the major educational problem raised? Does the material do what it is supposed to do? Unfortunately we do not know. We are convinced it will work with very general audiences, based on our library testing. Our information interviews of students who have used the material, conducted by skilled evaluators, indicates that at least in many cases students do succeed. In almost all cases the students are happy with the material. But no full-scale evaluation has taken place.

The following conversation between a student and an evaluator is typical.

I: I saw at the beginning you were just doing some experiments (i.e, trying to light the bulb), and now at the end here, you are answering all of these things right. I think you really learned something.

S: It's fun. It's better than in science, because in science we were doing this stuff and it was boring.

I: What were you doing in science that was so boring?

S: Well, we were doing positive and negative charges and stuff like that. And it really wasn't fun. But this teaches you some; it lets you try again and again. And it's not going to grade you or anything; it just gives you a lot of chances. I think it's better.

Much more extensive testing would be needed to determine changes in students' knowledge about the nature of science.

Another factor must be considered. These materials, no matter how good, will not solve the original instructional problem unless they are very widely distributed. At the present time that is not happening. We are currently talking with possible distributors about the marketing of these materials.

Success clearly will depend on their wide availability.

We believe that these materials are very promising, considering the problem we began with and the previous experiences with that problem. I do not see any other approach to the problem which has the potential of being so widely useful as this one. I regard this case as typical of many of our major educational problems.

Computers and Information Technology as a Learning Aid

For Study Conference of the Centrum Voor Onderweijs en Informatietechnologie

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It is a pleasure to return to Holland to both renew old acquaintances and to participate in the opening of your new Center for the computer in learning. Centers of this type are increasingly important in the world and Holland is to be commended for moving in this direction.

The computer will become the dominant way of learning in our society over a relatively brief period of time. That is, more people in the near future will learn more things from computers than from any other learning modes, including books and lectures. We are at the beginning of serious development of computer based learning material. In this paper I look at some of the key factors involved in this massive change in our educational systems.

Computers in Schools

First, let me note that computers are appearing very rapidly in schools all over the world. The most reliable figures from the United States, from the National Center for Educational Statistics within the Department of Education, suggest that at present there are approximately 150,000 personal computers in schools in the United States, about an average of two per school. The rate of purchase is approximately 100,000 per year, so this number will be increasing rapidly. In recent years, roughly speaking, the number of computers in schools in the United States has doubled each year. There is nothing remarkable, however, about the United States data. I understand that in England at the present time, for example, there are between two and three computers per school. While in the United States many schools still have no computer, perhaps half the schools, in England it is the government policy that every school should have at least one.

What happens when these computers appear in the schools is not necessarily favorable unfortunately. Two major problems, problems which will be important in much of what I say here, affect this. First, extremely little good curriculum material employing the computer is available. This is true whether one is looking at the teaching of programming, the teaching of broader aspects of informatics, or whether it is using the computer and some formal computer based learning material to learn some subject area not necessarily concerned with computers. The lack of first rate curriculum material involving the computer is a tremendous deterrent. Although much is now commercially available within the United States, this material can only be characterized overall as poor and often trivial.

The second major problem to be considered is related to this. Not only is little decent learning material using computers of any kind available, almost all the teachers currently in schools and all over the world have little experience with computers, particularly little understanding of how the computer is used in learning situations. A teacher whose only computer background was during a brief workshop or some short period of time is poorly prepared to teach programming because they have likely picked up a style of programming that bears no resemblance to good modern programming, and they often use a language that should not be used.

Computer Advantages

I have argued (in Learning with Computers, Digital Press) that the computer is a very powerful aid to learning in many areas. Although I do not intend to make a full case, it is important to mention the main advantages of the computer in education.

I regard the most important advantage as interaction. The computer can provide frequent and highly relevant feedback, based on exactly what the student has been doing. Questions can be asked and responses can be carefully analyzed, all within the common everyday language of the student. As numbers have increased in our educational systems, we have been less and less able to afford a highly compentent tutor who works with one or perhaps three or four students. Rather, we have moved toward mass production methods, where students play a passive role in the learning process.

For the first time by using the computer we have the possibility of providing an interactive education for everyone, not just the children of the very wealthy. This issue is

extremely important, not only in the developed countries of the world but in underdeveloped countries which need to make rapid improvements in their educational systems.

The two key issues in interaction are how frequently the student does something and the quality of each of these student-learning interactions. Not all interactions are equally useful in learning. Thus in our activities in the Educational Technology Center we avoid almost entirely the use of multiple choice, even in quizzing situations. We consider this to be an unpleasant form of interaction, one that has many negative aspects in learning situations.

One consequence of interaction is the possibility of individualizing the material. Most learning material delivered today in books, the typical classroom situations, treat everyone the same. But one person may want to move through the material at a different rate than another person, or one person grasps the material quickly but another needs other pedagogical strategies to understand what is happening besides the one used initially. Some students have weaknesses in background. Thus a student in a science class may not be able to use, in a functional sense, some critical mathematical technique. Lip service is paid in education to the notion that different students learn in different ways, but unfortunately our current learning structures do not permit us to react reasonably to this. The computer, because it is interactive and therefore pays attention to what the student is doing, can with well developed material individualize the learning experience.

This paper, examining the computer in education, will be concerned primarily with computer based learning. However, I wish to make it clear that this simply is a restriction in content, not a philosophical position. The computer can be used in many ways in learning situations. We have already mentioned the learning of programming and the learning of informatics. There are also very important tool-like uses of the computer, such as those employing word processing systems. In all these areas, good curriculum material is necessary for effective usage. But I will concentrate, as indicated, on computer based learning.

Some Examples of Computer Based Learning

I examine briefly several examples of the computer as a learning device. The examples from the Educational Technology Center at the University of California, Irvine, show learning in the sciences at two levels and different techniques. The first example is about six years old, a beginning quarter of physics for science and engineering majors. Students are offered a choice of a non-computer version and two computer versions which differ in content. About three-quarters choose the computer.

The course follows a mastery organization. For each unit the student has a list of learning resources and a description of what is to be learned. Students cannot continue to the next unit until they have demonstrated, through on-line quizzes taken directly at computer displays, that they know the material in a given unit perfectly. Four hundred students in the computer course take about 15,000 quizzes in the ten week period, with the computer generating each quiz uniquely and giving immediate feedback. All the record keeping and much detailed aid to the student, aid which is highly relevant to an error that the student has just made, is available. Students agree almost unanimously that the quizzes are learning material. Testing becomes a learning mode. In a sense, the tests are the course, in that they are the major learning facility for almost all the students. This way of organizing courses is possible only with the computer; it has considerable promise. It resembles the situation of pre-testing and post-testing, except that the two forms of tests plus the learning all take place with the computer based format.[2]

The development of this material was funded by the National Science Foundation.

The second set of computer based learning modules concerned scientific literacy, the nature of science. It is aimed at a broad audience, from young children through adults. The material has been widely tested in schools from junior high school through universities, and within public libraries and science museums.

When the science literacy units are used in the library no one is there to "help" the student, with either the computer details or with the subject details. Thus the materials are completely self running, and therefore also suitable for the home environment. The dominant pedagogical approach for the literacy materials was suggested by Robert Karplus a number of years ago, the learning cycle. Karplus derived these ideas from his study of Piaget in connection with the Science Curriculum Improvement Study materials. The learning cycle suggests three stages in the learning process. The first is experiential; the students have experiences which lead to better insight and which prepare the way for the more formal learning activities of the second phase. In the third phase students demonstrate what they know through testing or some other way and receive additional help if necessary. The student should also be able to apply the ideas to other areas. Karplus sees these three features as essential to learning.

There are six units available, each taking a student between one to two hours to complete on the average. Each of the modules has a subject area in science and mathematics, but, as indicated, the emphasis is not on the subject matter itself. The units are broken into fifteen minute modules, so the students can move around within the materials. The project was funded by the Fund for the Improvement of Postsecondary Education within the Department of Education in the United States.

The Educational Technology Center develops many types of materials, such as the two indicated here. We also are involved in research in using the computer more effectively in education, and we also consult with schools, universities, and companies on computer based learning. Some of this consulting involves the workshops to train people to prepare such material.

Production of Computer Based Learning Materials

A key factor for the future will be a system for producing very high quality computer based learning material at reasonable and estimatable costs. One of the difficulties with so much of the material available at present is that material is produced by

cottage industry procedures, and therefore often does not reflect the standards necessary for good learning material.

The major point to emphasize is that developing good computer based learning material is fundamentally no different from developing good curriculum material of any type. Thus to make an educational film or to write adequate text material is a long, difficult and expensive process. It is foolish to believe that there are short cuts to develop computer based learning material which would make it much cheaper that other competently done material. Many of the details of producing adequate computer learning material are similar to the details associated with other curriculum developments. Thus the pedagogical development stages and the various evaluation procedures are similar, no matter what the medium is, although we will point out some differences.

In understanding the question of computers in education, I find it illuminating to consider the history of textbooks. Textbooks revolutionized education, changing the major learning mode in almost all areas. Like our current interest with the computer, the textbook was based on a technological innovation, the invention of printing. In the early days of the printing press if a teacher wanted to use one of these new fangled things called a textbook, the only possibility was to buy a printing press and a set of type (undoubtedly the teacher was told that there was an easy way to use the printing press!) and to proceed to learn the art of printing. The teacher was probably not very good at this and only produced a few rather mangy books for use primarily in the teacher's own classes. Eventually a system developed and an industry developed around that system which removed the necessity for teachers to use the printing press. Today an author of a book is usually concerned just with the pedagogical details as reflected in the preparation of a manuscript. A very similar situation exists with the computer, with many close parallels.

I now make a few brief comments about the stages involved in developing good computer learning units.

1. Pedagogical Design

Two important aspects must be considered in connection with pedagogical design. The initial planning session may involve people from all over the country, engaging in a brainstorming activity; they create a specification document for each of the modules to be developed. It is important that research on learning and teaching in the subject area be examined. For good curriculum material we want to employ the best people in the entire country. This design specification can be sent out to competent individuals who did not draft it for review and for subsequent improvement.

Next is the detailed pedagogical specification of each unit. We generally do this in groups of three to five individuals. One or two people in the group will be highly competent teachers who have had much experience not only in teaching theory but also in reacting to individual student problems. One other person in the group might reflect the research background, and another person should be highly experienced in producing computer based learning

material. In the case of the Educational Technology Center this last person is usually a staff member of the center; other people involved may typically come from outside our group from other locations.

We find it desirable to do the design work in intensive one or two week sessions in pleasant isolated locations, avoiding constant interruption from telephones or other people. We want our designers to concentrate intensely on the activity. I will not discuss the strategies we use for recording the results of the design group. The specification of the units can be given to the screen designers and coders in the next stages in the process. This document can be reviewed as with the preliminary design document. That is, it can be sent to others with instructions on how to read it; changes can be made based on the suggestions received.

Some training of the detailed design group is needed, usually the first morning. The critical aspect is to understand the nature of the computer as a learning medium, mostly by looking at many examples of good and bad practice. We do not believe it is valuable to teach these people anything about computer languages whatsoever; the issues of the technical details associated with computers and the issues of how to use the computer effectively in a pedagogical sense are unrelated.

Nothing has been coded in this stage. One of the keys, we believe, to effective material is to separate pedagogical issues from technical or coding issues. The issue of how it is to be programmed should not influence the pedagogical design, the critical factor in producing high quality material.

2. Screen Design

An important aspect of computer units is how they are structured on the screen, both in space and time. The instructors, in some design groups, may make detailed design suggestions, but these suggestions usually do not give a complete specification of the screen. Instructors, indeed, may not be the right people to do it. Ideally, a good graphic designer, sensitive to educational issues, should be involved, working with interactive software particularly prepared for such individuals.

Often, however, in our projects at the Educational Technology Center, we have not been able to afford such a graphic designer. In such a case, a series of general principles will be useful, such as the following:

1. Use blank space freely--it is free on computer systems.
2. Remove any information not needed--the screen should not be a history of what has happened in the last five minutes.
3. Use as much visual information as possible to aid the student weak on understanding verbal information.
4. Use timing and other devices to stress key words or key phrases. Thus a key phrase might blink.
5. Use timing to aid readability. Stop when you have periods or question marks.
6. Use short lines to avoid reading errors.
7. Keep the natural phrases together on the lines, if possible, rather than splitting them across several lines.
8. Use a variety of textual styles, such as the occasional use of a text which is right justified but not left justified.

Screen design furnishes another stage where review and evaluation can be important. That is, the screen designs, created on-line by the designer, can be reviewed directly at the screen by other designers, and they can suggest changes to be be made.

3. Writing the Code

The next stage in the development process is to write the necessary programs to carry out the logic indicated in the scripts produced in pedagogical design. If there has been a separate screen designer, it will be not necessary to enter text material as that will all be present. Simple graphics will also be done, but the coder may need to do complex graphics such as that involving animation.

The basic principle in coding is that, as these are large complex programs which will need to be modified frequently (in the formative evaluation stage to be described later), and possibly transferred to a variety of machines, it is necessary to follow the best practices of modern software engineering. I do not review those practices in detail, since they are amply described in the programming literature. Unfortunately, most computer based learning material developers seem to be completely unaware of these practices and so a number of unfortunate directions have become common.

Programs should be written in such a fashion that they are as readable as possible. They should be written in a highly modular fashion. They should be amply commented. Variable names should be meaningful. Data types should be carefully specified and should be natural to the area involved.

As with any other well done complex coding activity, codes should be designed, perhaps by the use of such devices as structure charts, before any actual coding is done. This design can be reviewed and improved before the coders themselves work. A long program will probably have several different coders employed and one of the important aspects of this initial design is to coordinate their activities and to assure that the interface between their works are appropriate. After it is written, code should be reviewed, again following good modern programming standards and revised.

Given these factors, almost any knowledgable computer scientist would suggest that the programming should be done within one of the powerful higher level structured programming languages. Currently our materials in the Educational Technology Center are all coded within UCSD Pascal, a variant of Pascal very common on personal computers. Other good possibilities, although little used at present for this purpose would be Modula II or Ada. The particular language used is not as important as the fact that the language reflects modern programming standards; if it does not or if it is not used in satisfactory ways, the problem of improving the materials and transferring them may become insurmountable for an extensive set of learning materials. Some special procedures are useful in helping the coders here. Particularly, we find existing languages extremely weak on the issues of organizing the screen, and so we found it necessary to augment Pascal with a whole set of procedures for this purpose.

4. Review Evaluation of the Running Program

At this stage we now have the first running program. Two types of review and evaluation activities are critical at this stage, the internal review of the material and an external formative evaluation.

In the internal review the material will be run over and over by staff members of the project. They attempt to find out where the program does not work by trying many alternative branches. They will also see where the pedagogical ideas which seem good in the discussion group and on paper do not seem to be adequate in an actual running program. Emphasis on improving the interaction is important at this stage. Usually the program will go through many versions because of internal testing before it is available for full-scale testing with the target audience.

The formative review process is the first time that the units are used by the people it is intended for. The formative evaluation is perhaps the most critical of all the stages, except for the detailed pedagogical design, in assuring the eventual effectiveness of the material. One of the great advantages of computer based learning material is that it is still possible to make changes at this point because computer programs can be easily changed if they are well written. With books, for example, change is almost impossible after the book is printed.

The computer can collect much of the information in this initial testing with typical students. The student responses can be stored selectively, and so we can find where the program is not responsive to the student language. The students can be allowed to make comments. We can keep data on different paths taken through the material. We can do testing on-line to determine what the student has learned.

Other evaluation procedures are also useful. A skilled evaluator can interview students or can observe students' behavior. Detailed studies can be conducted using videotapes of students using the materials.

Several cycles of formative evaluation are useful. As increasing numbers of students are used in each cycle, the evaluations may become quite expensive, so budgetary considerations may restrict how much may be done at this stage.

The final summative evaluation is a more difficult issue. Good summative evalutaions are expensive. They should be done outside the initial group by competent evaluators and with adequate funding, so that sizable numbers can be involved in these tests. They should also not be performed until well after the materials are developed to allow the maturing of the product.

Authoring Languages and Systems--A False Direction

Before leaving the issues of producing computer based learning material, I wish to contrast a system of the type just discussed with another commonly used system which, I would argue, has been one of the main deterrents to producing effective computer based learning material thus far, the use of specially designed authoring languages or authoring systems particularly for such materials.

Hundreds of millions of dollars, and perhaps even billions of dollars, have been spent on developing such systems. With few exceptions, languages with large financial support (such as Tutor) have been used in writing materials. That alone should indicate that something is wrong with the approach.

The *initial* philosophy beyond many of these languages is a "Renaissance man" philosophy. Instead of the careful separation of tasks by using people of different abilities necessary for the type of production system envisioned in the last section, one person does it *all*. It is as if we were back to owning one's own printing press and preparing books! Developing curriculum material is a complex activity and cannot reasonably be expected to be carried out by a single individual, regardless of the medium envolved. Inevitably the pedagogical issues become, in authoring languages, confused with the necessities of programming and the primary decisions are *not* made on pedagogical grounds.

Although many of authoring languages and systems start with this single person philosophy, some recognize its limitations and begin to use a strategy more like the one reflected in the last section. Then the author no longer uses the system, but separate individuals are involved. Then the objections to the authoring languages and systems become quite different. They are then programming languages and they can be evaluated as programming languages, the same modern criteria we would use for evaluating any other programming language. The authoring languages and systems are mainly very primitive as compared with modern programming standards. They do not take into account what is known in modern software engineering.

Consider, for example, Tutor. Tutor is an old creaky language, dating from about fifteen years ago. Its structure is essentially that of an assembly language macro language, with a label field, a command field, and an argument field. It has a vast number of very complicated commands, over two hundred. No experienced language designer today would ever develop such a language! Yet Tutor has been the most widely used of all such authoring languages and probably also the most widely imitated.

Most authoring languages and systems allow one to use standard programming languages too. When this is the case, then often much being done within that language really does use a standard language, so the authoring system becomes less and less necessary. In the early days of Coursewriter I looked at an interesting program in physics concerning Gauss's Law. However, in getting the code, supposedly written in Coursewriter, I discovered 90% was in Assembly code for the IBM 1500.

Authoring languages and systems are often particularly weak for revision, a critical aspect of development. Indeed, with many of them the only possibility for revising a section of material is to redo it. The facility must be recreated on each new machine, often an expensive job, so transferability is not easy.

Eventually a language for computer based learning must have as a minimum all the capabilities of a general purpose language. So the writer ends up recreating a general purpose programming language with a few additions. It makes sense, therefore, to start at the other end with a good language and add a few special capabilities in the form of procedures.

Many of the developers of authoring languages and systems are not highly experienced with learning material. They often have a simplified view of how the computer can be used in learning, and the language they develop is restricted to that simplified view. As the view expands, under pressure of new materials, the language may be extended if funds are available. But then it becomes clumsy, as these new features were not taken into account in the initial facility.

There is a tradeoff, too, between how easy the language is to use and how restrictive it is on what it lets the author do. Thus, languages that are advertised as very simple, easy to learn by everyone, can usually only produce the most trivial material. This will become boring even within a single long program. Given the future needs for sizable amounts of computer based learning material, authoring systems are an unfortunate direction.

I now wish to move from this discussion of the current situation to consider the future of computer based learning material. In an area where the technology itself is changing rapidly, it is particularly important to think ahead.

Future Hardware

The computer, particularly the personal computer, is evolving very rapidly. Computers are not only becoming cheaper, but their capabilities are increasing rapidly. New systems will not necessarily be cheaper than they are today. Vendors will give us some balance between decreasing costs and increasing capability. Central processing chips are becoming more complex and faster, as we move to larger instruction size and larger data paths. Memory is also becoming cheaper and more compact.

Certain new facilities for the computer are important in connection with the future of education. Some are already available but need to be further refined or made more available. Others are future possibilities, existing to some extent in research laboratories but with much still to be learned.

Voice output is already available today but needs further work. A variety of strategies--analog storage, digital storage and phonetic recreation are in use. Except for analog storage, the voices still have an artificial sound generally not desirable for education. Voice is important in the learning process, so better voice output will be of some value. Music, particularly for motivational purposes, will be useful.

Graphics is still relatively crude, although typically available on personal computers. We can expect much better graphics--more choices of color, resolution, shading and intensity control and even general purpose animation as personal computers begin to use special graphic chips or use more powerful chips and more memory. Text too needs to be improved beyond our current rather crude text; choices of font and size of text should be available to the designer of computer based learning material.

Networking, at the local level and nationally, is just reaching the stage where it is practical. For years we have been hearing about the ethernets, and they are sometimes commercially

available now!

The combination of the optical videodisc with the computer, which I referred to many years ago as the intelligent videodisc, is a curious one. Although this technology has been around for about a dozen years, and although many people have recognized its potential in education, it has been so far relatively little used for the development of educational material. Much of the material that has been developed, particularly for industrial use, is relatively crude, with very weak forms of interaction. Full multimedia is an interesting possibility, and undoubtedly one that will be pursued further in the future.

Other forms of input will undoubtedly be developed. Painting input is becoming more common and undoubtedly will be improved. Voice input is possible for discrete speech but still is beyond our capabilities for continuous speech. However, it is being vigorously pursued in the research laboratory. If we can solve the problems of voice input, we may not need it, since from the computer's standpoint the analysis of complex voice patterns, and the analysis of complex brain wave patterns, are not necessarily that different.

Where Will the Curriculum Units Come From?

If we are to move from our current state where the computer is relatively little used in learning, almost at the level of trivia, to a state where the computer is very heavily used, we need to ask where the new courses and curricula will come from. The production system outlined is intended to be adequate to produce sizable amounts of curriculum material of high quality.

But many other issues are involved.

1. The Producers

Who will produce this new computer based learning material? At the present time some of it is being produced by individuals, teachers and university professors, and other materials are being produced within companies, textbook companies, computer vendors and new companies which have been developed particularly for this purpose. Another possibility is the development of national centers, perhaps with government support, for such developmental activities. The Carnegie Commission report about a dozen years ago, "The Fourth Revolution--Instructional Technology in Higher Education," proposed that seven such centers should be established in the United States and that they should receive one percent of the total budget for higher education. Such centers now seem politically unlikely within the United States, but they have greater possibilities within some other countries.

The interests of the publisher is in protecting existing educational markets, so many publishers are already making investments in this direction. But they remain relatively uncertain about how to proceed, fearful of making mistakes in an area where little marketing data or experience is available.

The computer companies, too, are fearful, but perhaps less fearful since they are familiar with the technology. They see the production of computer based learning material as a way of making certain that more hardware is sold and of developing another market in software as the cost of hardware continues to go down. Initially there were some allegiances between

publishers and computer vendors, but the interests of each was different. So such companies are often not satisfactory.

2. The Distributors

The issue of who will distribute the materials is a different issue. All the same "players" already mentioned are possible, but a given group might decide to play a role either in production or in distribution or in some combination of the two.

Distribution brings in questions of protection from copying, either through technical means or through legal means. We do not know if the copying of computer based learning material will be a serious problem or not, since our experiences are so small. We do know, however, with other kinds of software, that a market may exist in spite of copying. Spreadsheet programs have sold well over half a million copies, although they are on floppy discs that could be easily copied.

3. The Home Market

In considering educational materials, it is very important to take into account the growing home market. The home computer will need a variety of applications oriented programs to make it marketable. One of the categories in which such materials will be developed is education. Products of this type will be widely available and will affect what happens in the schools. There may be products usable in both home and school.

Educational Institutions and Organizations

It is impossible to imagine a change of the magnitude predicted here, the computer becoming the dominant educational delivery system, without anticipating massive changes in our current schools and universities. These changes are not likely to occur from internal pressures, as educational institutions are very conservative, slow to change. Even educational institutions most in favor of changes promote relatively trivial changes that do not fundamentally affect the institutions. We can expect, due to the current severe problems in education, including both financial and public opinion difficulties, that very strong external pressures will encourage change, particularly regarding the use of the computer. These changes will be particularly accelerated in the United States if such radical systems as the voucher system come into widespread use.

We already see a number of nontraditional ways of organizing universities. The most interesting are learning at a distance institutions, such as The Open University in Great Britain. Within existing institutions there will be changes, particularly in the way the courses are run. The notion that a course should take a fixed amount of time will probably vanish as flexible, individualized computer based learning material is becomes available. Computers will be more used in schools at all levels. Changes in grading systems, made possible by the fact that much more is known about the student and the student's problems, may well happen, shifting from norm-based grading to competency-based grading.

It is quite possible that with the new learning materials there will be a shift in the _arena_ of education. That is, less education will take place within formal schools, and more will take place either in public environments, such as public

libraries or the home. The learning at a distance institutions already represent a move in this direction. Not all education will move out of the school, but certain components are good candidates for such a move.

The Future--Good or Bad?

Although it seems clear, for reasons not fully discussed, that the computer will become more important in education, it is not yet clear whether the computer will improve education, helping to overcome some of our current problems, or whether it will lead to further deterioration in the educational systems of many countries. The effectiveness of the use of the computer in education may be an important factor in determining which countries will succeed in the future.

There is nothing magical about computers. Like all technological developments, the computer itself is not good or evil. Rather it is the way it is used by humans which is the critical factor, in education or elsewhere.

The poor quality of much existing computer based learning material and the widespread acceptance of this material by teachers and administrators gives us cause to worry about the future. If publishers distribute third-rate material and this material is eagerly gobbled up, publishers have no incentive to develop better material. It is critical to educate teachers to understand the quality of the materials, to look at computer materials critically, just as they might look at other kinds of educational material.

This material is "reviewed" to some extent today. Most of these reviews are in magazines which are heavily dependant on the vendors for advertising. So it is not surprising that most of these reviews are positive. I remember seeing a review, for example, recently about a new Pascal. The person had just studied Pascal and had taught BASIC for years, hardly the person one would want to review Pascal.

If we are to move toward a better future in education, we must look at new ways of organizing our entire educational system. Yet relatively few such visions of the future are available, and the vast majority of teachers with computers have no view of where they would like education to move.

One view that I recommend to readers is in George Leonard's book, Education and Ecstacy. Two chapters portray a school at the beginning of the next century. While the technology that Leonard portrayed has been to some extent surpassed, because of the quick rise of the personal computer, the educational ideas are worth looking at.

This presents only one view of the future. It is hoped that readers will develop their own visions and that they will take an active role in moving us toward a better educational system.

TWO EXAMPLES OF COMPUTER BASED LEARNING ON PERSONAL COMPUTERS

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Biography:

Alfred Bork is professor of Information and Computer Science, professor of Physics, and Director of the Educational Technology Center, all at the University of California, Irvine. The Educational Technology Center is internationally known for its development of highly interactive graphic computer based learning materials in a variety of levels, subject areas, and modes. Bork is the author of Learning with Computers, available from Digital Press (Digital Equipment Corporation, 1981) and of forthcoming Personal Computers in Education, to be published by Harper and Row, in addition to many articles and other books.

This paper concentrates on two examples of computer based learning, both developed at the Educational Technology Center at the University of California, Irvine. Both are intended for a very wide audience, but have been primarily tested with junior high, high school, and university students. Both sets of modules

concern important educational problems, problems which have proved difficult to solve in any other way in our educational system. The products are essentially complete; all the material can be inspected on developmental systems. We are currently moving these units to delivery systems.

The two projects address scientific literacy and with aiding students to become formal reasoners. The first is supported by the Fund for the Improvement of Post-Secondary Education and the second by the National Science Foundation.

Both projects, in addition to extensive testing in schools, have also been tested of public environments, principally in public libraries and science museums. The modules are designed to run entirely self-standing, with no teachers, print material, or other aids available. In the libraries, the computers are simply sitting there and library visitors come up and begin to interact with the computer.

Thus the materials must maintain the interest of the viewers; they must be be strong motivationally. They do not require any special knowledge about computers, as anyone coming into the library is a potential user. Furthermore, they must not have any hidden assumptions about what is necessary to understand the subject matter areas but must accept all students where they are.

A typical module lasts, with the average student, about 90 minutes to two hours. Modules are divided into a series of sub-modules, usually 8 modules of about 10 to 15 minutes each. The units are coded in UCSD Pascal. The programs are highly interactive. The average time between interaction in our programs is approximately 15 to 20 seconds. Thus the student is always being asked to do something, therefore the situation is extremely different than that of a book or a lecture. We are also concerned about the quality of interaction in our programs. Thus we never use multiple choice, as we consider multiple choice to be a very low quality interaction, even in testing.

Considerable consideration is given to the visual appearance of both the text and graphics on the screen to aid the learning process. Thus, large amounts of blank space are used, lines are short, lines end with natural phrases, and no hyphenation is used.

The production system that led to these materials follows that which has been developed for many years at the Educational Technology Center. Further descriptions of the production strategies are available on request, and it is described in considerable detail in the two books by the author mentioned in the bibliography [editor: are these bibiligraphies really to be printed with the paper or should we repeat the references here?])

SCIENTIFIC LITERACY

Our society is heavily dependent on modern science and technology. Yet our educational system does, at the present time, an inadequate job of helping the vast majority of people in our society to understand what science is all about. It is much easier, both in the schools and the universities, to deal with the factual areas of science, to expound the laws, and to teach people to solve problems, than it is to give any overall feeling

as to the nature of the scientific enterprise. Only a few courses have attempted to do this, such as the high school Project Physics course developed at Harvard University. Most courses in the sciences give only lip service to getting students to understand the nature of science.

We view this to be an important national problem, one that is not being addressed effectively in our current educational system. Some of the earlier attempts to address the problem of scientific literacy in the general population, such as seen in the Elementary Science Study Program, Science Curriculum Improvement Study, and in Science, A Process Approach, have now very little use in American schools.

The Educational Technology Center realizes the importance of this problem and for a number of years sought funding to develop computer based learning materials to deal with this important and difficult issue. Finally we were successful in persuading the Fund for the Improvement of Post-Secondary Education to support the project. They were interested partially as an adult education project, because of the use of the materials in the public libraries. But I believe they were also attracted by the potential of the same material serving a very wide audience from young children through mature adults.

Although the various units work in a variety of subject matter areas, the general tactic in most of the units is the same. We attempt to place students in an environment in which they must behave like scientists in their approach to problems. Usually one or more of the early modules starts with the gathering of empirical information through built-in facilities in the program. These experiential controllable worlds (similar facilities are called microworlds by some authors) allow learners to play with the phenomona involved and develop some evidence. Then, based on this, we encourage the development of hypothesis on understanding the evidence.

It is critical that the scientist not only observe but also develop models and theories which account for the observations. In this model-building activity within the dialogs, the students receive considerable help. We want every student to succeed, provided that an honest effort is made. As hypothesis are developed, tentative models, a student can then test these against the empirical situation. It may be that the hypothesis will need to be modified.

In some cases, we "mislead" students so that they will initially develop "false" hypothesis which account for the evidence already gathered, but will not account for future evidence. Thus we try to give some of the flavor of failures of science, as well as the successes.

As the theory or model is developed to account for the evidence, the emphasis shifts to the predictive power of scientific theories. The students must make predictions using the theories that have been developed and these predictions are compared with the experimental situation.

In most cases the apparatus is simulated on the computer. We hope later to do some detailed studies of the effect of actual apparatus versus simulated apparatus. We considered this question carefully in the early stages of development. In viewing the earlier projects which had not succeeded, one of the problems was that, regardless of the desirability of undesirability of equipment, many teachers did not want to use the equipment, and indeed, refused to make use of the kits of apparatus.

The presence of the equipment would present logistic problems in libraries, or in what we regard as perhaps the most important eventual use of these materials, in home use on personal computers. Some decided, in most cases, to simulate the equipment.

Some of the ideas involved in the earlier curriculum projects were very useful to us. Thus, we developed a Batteries and Bulbs module following quite similar strategies to that developed in other discovery oriented projects in the '60s. We were able to profit by bringing in teachers and developers who had extensive experience with the earlier curriculum materials. Some of the modules concerned actual scientific situations, but in other cases we deal with imaginary situations, theories which do not exist in nature, or theories which exist in nature but that the "evidence" we present is not actual evidence but fictional evidence.

As an example of this last type, I will describe briefly one of the modules, Tribble Families. This module starts with fantasy. The student is the chief scientist of a spacecraft, which descends on a strange planet and finds a number of peculiar looking animals called Tribbles. In the first unit of the program, the task is to classify Tribbles, noting differences between Tribbles. The Tribbles, unlike any animals seen before, differ in only three characteristics: eye color, size, and horn shape. In the second module, the task becomes that of finding out which Tribbles, when put together, have children and which don't. As with everything else in these modules, this topic must be approached purely empirically. The students are never "told" things but rather must gather data by putting Tribbles together and seeing what happens, then they try to generalize on the results that they see.

Eventually, Tribble families proceeds to develop a Mendelian genetics theory. The approach is very different than that in a typical biology class. The students are not told the underlying theory but rather it comes out of study, somewhat the way a scientist might do it. We cannot, of course, be fully realistic, but we can, and we believe we do, give the flavor of what it is like to work in science.

The project manager for this project was Barry Kurtz.

FORMAL REASONING

The second project is concerned with the recent finding that many students in the United States do not become formal operational in the sense of Jean Piaget, at the age, approximately 12 to 14, where Piaget says it should be happening. Particularly recent studies in different parts of the country of college students, using the Piaget formal operational tasks, show that as many as half of the students in universities, either at the freshman or senior level, are not formal operational. Yet if

one examines the content of many freshman courses, particularly in the sciences, we see that the formal operational traits, such as ratio reasoning are heavily used in these courses.

As in the previous project, my colleagues and I at the Educational Technology Center saw this as a serious national problem and one that was not likely to be solved by the conventional classroom methods. It is our suspicion, although I do not know of very much in the way of formal evidence, that many teachers are themselves not formal operational. So it is unlikely that these teachers will be likely to help students become formal operational. We saw some possibility that the computer could help with an important problem that was difficult to solve with traditional learning methods.

Each of the modules is based on one of the Piaget formal reasoning tasks. Each involves some subject matter area in the sciences or mathematics, so the materials could be used within science or mathematics classes. Experience before computer material has indicated that a single subject area is not sufficient for the student to develop a concept. That is, if they learn, for example, about ratio reasoning in one context, it does not necessarily carry over into another context involving ratio reasoning.

Hence, in some cases, we have been able to develop several modules in different areas. Thus, ratio reasoning is represented in this project with two modules, one based on the concept of speed and one based on the concept of density. Two will will not be enough for our purposes, but as with all projects, we had a finite amount of resources to work with!

As an example from this project, I consider the speed module just mentioned. This module was based on earlier work of David Trowbridge for his doctoral dissertation at the University of Washington. The first sub-module is again experential, with the student allowed to fire balls in different ways with pinball-like mechanisms with particular tasks assigned in the process. The notion is to build up some intuitive conception of speed. In the next module, we consider situations in which the time is held constant but the distance can vary. Then we consider the opposite case, situations in which the distance is held fixed because the balls travel in tunnels of fixed size but the time is variable. In each case, students are presented with large numbers of examples and must decide, given pairs of motions, in which cases the balls move faster or slower.

In later sections of the dialog, both space and time are allowed to vary so the true ratio idea enters. Facilities are provided for both space and time in some of these modules. Project Manager for this project was David Trowbridge.

CONCLUDING REMARKS

These two projects illustrate some of the developmental activities of the Educational Technology Center. We have, at any given time, a range of research and developmental projects active at the Center. Those interested in our current projects are invited to write for further information.

COMPUTERS IN LEARNING--COMMON FALSE BELIEFS

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1. The real problems with computers in schools are those of getting enough hardware for the schools--enough computers for each school.

The number of computers in schools has been doubling or tripling each year for the past several years, in spite of the stringent financial conditions of schools. We now have approximately 300,000 computers in schools, averaging about three per school. Although numbers are increasing rapidly, the sophistication of usage within schools is often primitive. Teachers are often ill prepared to use the computer. Very little good instructional material is available. Teachers have low standards for selection of instructional material. Inadequate programming techniques are often being taught, crippling students for later programming activities.

This is not to say that some good uses do not occur in schools. But on the balance it may turn out that at the present time the students are being hurt more than they are being helped by the computers in schools. More machines will only compound that problem.

2. Any way the computer is used in classes, or other learning environment, is good.

The computer, like any other learning aid, can be used in ways which are helpful to student learning or ways which are harmful to student learning. There is nothing magical about having a computer.

A computer with poor curriculum materials, or teaching the material in inadequate ways, can be devastating to students. Likewise, teaching inadequate programming techniques, no longer used in practice, can hurt student's progress rather than aid students. The use of any educational device in the classroom must be evaluated on its own merits, regardless of what kind of learning technology is used.

3. The computer can be used in only one reasonable way in classroom environments.

Adherents of various points of view often have this belief. That is, they believe that other ways of using the computer besides the one that "they" favor, are intrinsically wrong. Decisions about how to use computers for learning should be made entirely on pedagogical grounds, not on predetermined philosophical positions.

4. All students should learn to program.

As computers become more and more widespread in our society, the vast bulk of usage is likely to be the use of very powerful computer based intellectual tools. Our current tools, such as word processing, spreadsheets and personal data bases, are only beginning to show us the real power of such tools. Because of these tools, most people will not be involved in programming itself.

Programming is often justified on the assumption that it helps to give students some idea of what computers are all about. But this is not true. Most introductory programming courses, even extensive courses, do not give a full picture of what is possible with the computer. Often the applications tools, just suggested, give a much better idea of the real power of the computer.

5. Because it is easily available on small computers, we should teach students BASIC.

One of the major disasters in current schools is the teaching of BASIC. Almost all BASIC teaching in schools is developing a series of very fundamental bad programming habits that are difficult for students to overcome later. Most students who study BASIC in high school have difficulty with computer science in the university, or in any other modern programming applications.

6. We know all about how to use computers in education.

Our knowledge of the learning process is weak in many respects. Conflicting theories of learning still abound. Furthermore, much is still to be learned about the computer itself as a learning device. Additional research is needed. This is not to say that we should stop doing any development until the research is complete. In fact, I do not believe that we can afford to do that at the present time, perhaps because the research may not be complete for hundreds of years.

7. Teachers can develop extensive curriculum material in their spare time.

A legend has sprung up suggests that teachers will be able to develop large amounts of computer based learning material. Indeed, the programs in many schools are predicated on this unlikely assumption. The development of any type of good learning module, involving the computer or any other learning media, is a process that requires much effort and care. Hence, very few people, including teachers, are likely to be able to develop extensive computer based learning material in their spare time.

8. If a program draws lots of pretty pictures, it must be a good program.

Although I have long argued for the importance of graphics in education, some recent learning programs are almost nothing but a set of pictures, unrelated to the learning material. While visual information is important in learning, the developer must work hard to make certain that the visual information is an aid in learning and is not just a gimmick.

9. Authoring languages and authoring systems are useful in producing computer based learning material.

Most authoring systems and authoring languages intended for pedagogical design are toys, allowing the production of only restricted types of computer based learning material. Furthermore, they tend to confuse the issues of pedagogical design, with the technical details of programming the material. More adequate authoring systems exist. Software to aid the coder, on the other hand, can be useful.

10. We cannot write useful computer based learning material

until artificial intelligence techniques are practical for general classroom use.

Although some of the techniques of artificial intelligence will probably eventually demonstrate their usefulness in computer based learning material, we can already develop, without such techniques, highly effective learning material dealing with very difficult learning problems. The computer is at least as intelligent as any book, even in its least intelligent form, and books have long been shown to be very effective in the learning process. Programs can reflect the intelligence of very good and experienced teachers, without requiring built-in intelligence.

11. Since computer "Alpha" is common in schools, all curriculum materials should be developed for this computer.

The number of computers in schools tends to double or triple each year. Furthermore, new models are appearing constantly, so any curriculum effort which bases its thrust on computers currently in schools is soon likely to be in difficulty. It is essential to look ahead.

12. Computers will certainly improve education.

As already indicated, the computer is not necessarily a desirable force in education. Computers can lead to a better educational system, or to a worse educational system than we have now. It is only that if we insist on the highest quality, both commercial and non-commercial products, that we are likely to improve education with the computer. The issue at the present time is very much in the balance.

GRAPHICS AND SCREEN DESIGN FOR INTERACTIVE LEARNING

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ABSTRACT

This paper concerns the role of graphics in computer based learning material. We consider both textual and graphic components of screen design and both spatial and temporal aspects. Informal design standards are developed. Several software approaches are discussed.

COMPUTERS AND OLDER MEDIA

The computer's use as a learning media is just beginning. It promises major changes in our educational system. Every new learning mode, such as the computer, has unique properties. This paper addresses those aspects of learning via computers that are particularly concerned with spatial and temporal aspects of display on the computer screen.

The computer screen is the arena for spatial and temporal display of information in computer based learning for both the computer and for the user. (We may also have sound information.) On the display we may find both iconic (pictorial) components and textual components. The way information is placed on the display can have a great effect on learning.

The computer as a learning medium is very different from older media such as books and lectures. Thus, the computer screen is very different from the page of a book. Successful curriculum developers in older media treat the new medium just like the older one, carrying over successful tactics from previous use: the screen is often formatted like the page of a book. It is only by conscious effort that we begin to understand the great differences between the computer display and these older media. Some differences reflect different capabilities. For example, as soon as a reader turns the page of the book, the entire information on the new page appears at once. The computer display is extremely different; information can develop in time, under control of the computer and the user.

A second difference concerns cost. Things which are possible in new and older media may be practical in one and impractical in another. Thus, while sophisticated designers understand that blank space in books aids learning, the amount of blank space in books is rigorously controlled for financial reasons. One cannot afford to put only a few words on each page, even if that were the most effective way to promote learning, because the cost of a book increases as the amount of blank space increases. However, with the computer screen no such relationship exists between the amount of blank space and the cost. Hence, blank space, while possible in both, can be used much more freely with the computer.

Even a cursory review of much current computer based learning material shows that the developers often are blissfully unaware of the differences between books and computer displays. The usual procedure is to start at the top left corner and to put the information densely on the screen at the maximum possible speed. The computer "pages" thus resemble the pages of a book. Few authoring systems give developers any capability for better control of this medium.

Often decisions are made purely on a techological basis. Thus, many developers of computer based learning material appear to believe that the faster the information appears on the screen, the better. This does not match our experiences at the Educational Technology Center with young novice computer users. We suspect that fast output reflects a desire to use the technology to make the computer presentation look more like a book presentation.

CHANGING CAPABILITIES

In dealing with the computer as a learning medium, we must recognize that its capabilities are improving rapidly with time. Some of this improvement, such as faster and cheaper processors and more memory, simply refers to general computer capabilities. These factors will influence the effectiveness of the computer as a learning medium.

It is a fundamental mistake to consider today's small personal computers--the PET, the Radio Shack, or the Apple--as typical of personal computers in the very near future. Any realistic consideration of screen characteristics must look into the immediate future and must make some reasonable assessments as to what will soon be available.

Developmental strategies must take into account the changing nature of the medium. Thus, the development should be done in such a way that it is reasonably easy to incorporate into new versions of the learning units new capabilities not available at the time of development. The programming must ensure that it is relatively easy to modify the code; the question of how to program in a dynamic environment where changes are expected is the major issue. Indeed, in most major applications areas the cost of maintaining and revising programs over their life cycle is likely to be greater than the cost of initial development. The criteria we need to consider are the same criteria used in large-scale complex programming.

We can delineate areas where we can expect screen capabilities to be improving in the near future. Consider first characeristics of screen graphics. Current graphics on inexpensive personal computers are limited by poor resolution, low speed, inadequate numbers and control of color, the lack of shading and intensity control, and the severe limitations on animation. We can expect all these to improve. Several technological factors are important in this improvement. First is the separate processing unit to handle the display. These processing units may be designed for graphic capabilities, such as the recently announced NEC chip. It is reasonable to expect competitors.

Another factor in the rapid improvement of visual quality is the decreasing cost of memory. Screen resolution in a raster system, storing bit maps of the screen, can improve as the cost of memory comes down until the limits of current video tube technology are fully realized. Beyond this point we need inexpensive, higher resolution monitors. This may be a slower process, because we cannot piggyback on the large TV market.

As increasingly powerful processors stop using low quality monitors to control the display, the importance of languages which allow multitasking will increase. Many graphic activities could be improved by using separate graphic processors. While some aspects of separate use can be handled without tasking capabilities within the developmental language, to make full use of separate processors it is necessary to start separate processes and have them proceed independently.

Character display capabilities will also improve, although not as quickly as graphics. Currently computer users have mostly an abominable set of characters on the screen, characters which would be considered completely unacceptable in the print medium. The main concern of those designing character sets seems to have been to make certain that an "A" is distinguishable from a "B." Thus, hundreds of years of print character technology has been lost in most computers.

This situation is changing. We now have experimental systems capable of different character fonts, and we also have systems which allow user choice of characters. We are also beginning to see systems that allow choice of size and color of characters and other similar features. The character problem is connected with resolution, already raised with respect to graphics. We may expect major improvements in quality of characters to come from Japan, since Japanese characters require better resolution than those in western alphabets.

A third area for improvement is the development of new and better forms of input and output. Thus, we are very much looking forward to greater availability of voice output. Voice output, such as that available from Texas Instruments, is rare on personal computers. High quality music is available but also rare. Several current projects are considering voice input, but none can be expected to reach full fruition for personal computer use for many years.

Personal computers are often weak in pointing devices, and additional work and study in this area is needed. Some widely touted pointing devices, such as the finger, have relatively poor resolution. Others are difficult for the novice to use.

Based on these future considerations, we can ask about reasonable design standards for computer based learning. Our design standards will include both the spatial and the temporal aspects, since both space and time are controlled by the designer and (possibly) the user.

REASONABLE DESIGN STANDARDS

The design standards specified in this paper are based on extensive experience at the Educational Technology Center in developing a large amount of computer based learning material, both initially in the timesharing mode and more recently with personal computers. During the fourteen years in which our group has been active, we have considered design issues very seriously. Recently we have been fortunate to have funds for experimental studies from the Research in Science Education program in the National Science Foundation.

The first thing to be said is that design standards for computer based learning material should be the standards of good graphic design in any application. By good graphic design we mean the standards that would be followed, for example, by an excellent designer in producing an ad for a high quality magazine, but as appropriate to the new medium. The necessity for such standards in computer based learning is not generally recognized. Nevertheless it is important in effective use. A corollary to this comment is that a professional designer should be employed in the development of the highest quality computer based learning material. We consider later the environment in which the designer should work.

We can formulate a basic general design principle, applicable to all the material that follows. Since we are concerned with learners, we want the learners to focus on what is important, whether this information be visual or textual. The implication is that we should remove unnecessary information from the screen, and only show at a given time material important for the learner at that time. We do not need to follow this rule slavishly, but it furnishes a good guiding principle for the developers and for the graphic designers.

ICONIC INFORMATION

One aspect of what appears on the screen are the images, the pictures to aid learning. Here too we can state a general principle. We want to use as much educationally relevant visual information as possible. Much of the learning experience should be carried by visual information. This message is one that the pedagogical designers as well as the graphic designers must keep in mind. Redundancy--information in both forms--is desirable.

The tendency unfortunately is in the other direction. Since many curriculum developers are the successes of our current highly verbal educational system, they tend to be verbally skilled, more skilled than many students. Therefore, they often do not realize the necessity of good pictorial information for the average learner. Many people who are "failures" in our current educational system could be successes in a system which paid more attention to the uses of visual information to aid learning.

It is still not easy to satisfy this need for inconic information. We must keep focusing the designers' attentions on pictorial design. Material that is heavily verbal can be sent back to the pedagogical designers, prodding them to give more consideration to visual components to aid learning. On the other hand, pictures should be relevant to the learning process, not just pretty pictures.

Several features of the use of pictorial information are unique to the computer, as compared with books. Some are devices which are well-known on the blackboard or on TV.

For example, it is not necesary for pictures to appear instantaneously. Material can develop in time. Often the text and pictures can be interwoven with parts of pictures coming on in response to specific references in the text and with suitable delays in between. Timing can emphasize critical features of the pictures by delaying before and after those critical visual features. We can also highlight these critical features or make them stand out in other ways such as blinking.

Another factor derived from studies which preceded computer use is that a picture can have too many details. That is, details which distract the student from critical features can cause learner problems. In any picture we must identify the critical features and ask how these can best be brought out by the way a picture is presented. We ask if a given detail is really essential, or whether it can be omitted.

TEXTUAL INFORMATION

The pictures and text cannot be considered separately. They both contribute to learning, working together.

Perhaps the major consideration with regard to texual information is that we should use large amounts of blank space. A given screen should be relatively sparse, both textually and pictorially, at any one time. Much of the area on the screen should typically be blank. As indicated above, one way to achieve this is to eliminate the information from the display no longer needed by the user. Often we see screens which contain a large amount of "past history," not relevant to the current situation. This is neither necessary nor desirable.

A second consideration is that text should be placed on the display with the same care that would normally be used in placing a picture on the screen. Text placement should not be a system accident. Software for computer based learning is poor if the system decides where text is to go and how it is to be displayed rather than the pedagogical designer, the graphic designer, or the learner making this decision. Conscious placement of text, allocation of display information, should be considered at all stages in development.

Strategies to increase comprehension with print material are known. Although little definite information about these strategies refers specifically to the display, it seems reasonable that previous print readability research will be applicable to screens. Thus, short lines, requiring less eye movement in reading a line, are generally desirable. Avoiding hyphenation is highly desirable--hyphenation is a barrier to comprehensibility. Keeping natural phrases together on a line is also another important consideration; the phrases can be defined syntactically or semantically where the experienced reader will pause. Justification at both ends of the line is also undesirable.

A variety of methods, again both spatial and temporal, are available for stressing material on the screen. Thus, there can be a pause before and after a critical word or phrase or the word or phrase can blink or it can appear in bold or in some other way, such as an alternate font or color, that sets it off.

An important consideration, unique to the computer, is the quantity and degree of viewer control allowed in the display text. In all of our current programs we allow the user to choose at any time the rate of text output. The decision followed by young students is often different from that provided by most developers of material--the typical person not acquainted with computers prefers a much slower rate of text output than is usually seen.

Students can control not only the overall rate of text output, but also the timing between words and other aspects of timing. Furthermore, many of the features stressed in the last paragraphs also can be turned over to the user. The question of which of these is most important for increasing comprehension and motivation needs additional investigation. A current research project at the Educational Technology Center is considering learner control.

To maintain interest we can vary the style of display with size of the type, fonts, and varying alignment or justification procedures. So the learner doesn't see the same old thing repeatedly. Varying style has strong motivational components. Our software for text output at the Educational Technology Center supports three justification modes: Left justification (without right justification), right justification (without left justification), and centered text, the text centered on the line within a particular area of the display. We use specified areas, ports or windows, with a strategy similar to that used for display of graphic information.

For student text input, our group borrows from good word processing practice. Text input is always in a "port," an area on the screen as just described in connection with output. The port for input may or may not be the output port. The software handles wraparound like word processors; if students type a word too long to fit within the port, they see it on the current line until the edge of the port is encountered. At that point, without any fuss, the partial word is moved to the next line and students can continue typing with no need for any special action.

Timing is also important on input. We want a user to be reminded of what to do in many situations ("Don't forget to press return!") or given other specialized time-dependent aid. On the other hand, the software should not cut off someone currently typing, even if a sizable delay preceded this typing. Again, these factors are in the Educational Technology Center software and so are in all of our programs on the personal computer.

THE DESIGN PROCESS

Several individuals can be involved in design. The visual design components come from at least two groups in the design process. In the pedagogical design component excellent teachers, curriculum designers, and others work closely together to develop the necessary pedagogical specifications. They must be concerned with any factors which they believe will influence learning. Among these factors are the factors of design in both space and time.

We encourage pedagogical development teams to specify any design details they regard as critical for use. Of particular importance, often determinable only by someone with special expertise, is the question of what needs to be on the screen at a particular time.

The pedagogical design team specifies design details in two ways. First they may draw sketches of the screen, showing approximately where pictorial information and various types of textual information are to appear. In some cases the pedagogical designers will give this information in considerable detail. In addition visual information, the scripts produced, can also contain extensive verbal instructions for the visual designer or for the coders, timing considerations or information about where.and how things are to appear on the screen.

We run a half-day, informal workshop for our authoring groups, before the full pedagogical design process. One of the components stresses the display design details that form the basis of this paper.

The amount of screen design input which comes from the pedagogical designers will be variable. Some individuals are very conscious of these issues and will give them very careful specification. Other groups will almost entirely ignore these issues. So the quality of visual and temporal design at this stage will vary.

The next person who may be involved is the graphic designer, an individual with a good design background in other media. This individual also needs to understand the educational implications of design, implications which often are not part of the standard design curriculum. So it may be necessary to train this person. Unfortunately we are not often in a position to afford a graphic designer. Much of our materials have had to rely only on general design principles as stated rather than on the insight of a graphic designer. As we move toward more large-scale development of computer based learning material, graphic design will be a critical feature of the full-blown production system.

DESIGN SOFTWARE

If graphic designers are to function effectively, they should be working on-line, creating in an easy-to-use system the actual displays that the viewers will be seeing insofar as these displays can be determined before user input is known.

If the designer is to work interactively at the screen, special software must be provided. We have developed a variety of such software at Irvine, although we are still not satisfied with it. Several systems developed at the Educational Technology Center will be described briefly.

The first graphic design language was developed for timesharing, initially as a picture editor by student programmers working with a program where many pictures were necessary. It evolved into a general display editor, used extensively for several years.

This facility, a series of APL functions, allows users to create, modify, store, and delete objects, either text or pictures. All objects can be referred to by names.

The user interactively constructs objects needed for a display, placing them in the desired locations. They can be easily moved. When the design is complete, it is "pasted down", just as a graphic artist might do in developing an ad for a magazine. While most objects came through functions, tablet input is available for drawing objects.

The program is a code generating program, writing commands in the macro capability that we used in our production of computer based learning units. It stored the full graphic data, since we were working on a timesharing system with adequate file space. It wrote either in-line code or three types of procedure calls, depending on whether the object's position was known at the time that the designer was working or whether the position depended on choices known only when the final dialog was actually run.

We also developed learning sequences to aid people to become familiar with the facilities. The most successful was in print form.

When we shifted from timesharing systems to personal computers, we created tools to support efforts on these smaller machines. In this area, we initially developed three tools: a text display package, a graphics display package, and a graphic design system. The last was intended for the designer.

The text display and graphic display package are similar. Both support the goals of effective screen design, transportability, software maintainability, and simplicity of use. The vocabulary and programmer interfaces for the two are consistent and new programmers are able to use them effectively after a single introductory course in programming. These packages provide a uniform and "friendly" user interface where the display of information and handling of input is controlled in a manner dictated by sound instructional and graphic design. The graphics procedures were motivated by the ACM SIGGRAPH core graphics standard.

The graphic design system allows definitions of the position of ports and objects to be displayed. The design of the system is based on three concepts: the importance of screen layout, the hierarchical design of displayed objects, and a hierarchical display interface.

Most graphical objects have naturally hierarchical composition with "natural" sub-objects. Eventually one arrives at primitive constituents, such as points and lines. This hierarchical structure facilitates creating and editing of graphical objects. Pictures can include other objects, which may be selected from libraries of previously defined objects called "sketch books."

Users are presented with choices from a tree of menus, graphics related functions together. The cost is that one must know something about the overall organization to know where a particular function is located. To alleviate this problem and that of possibly needing the same function at different places, commonly used functions were made available from multiple places.

To protect from mistakes, designers can "back out" or undo most actions. For example, when an object is edited, only a copy of the object is changed until, after viewing the fully edited object, the user requests that the changed version be "saved." The ability to "back out" is implemented at every level. Development is still proceeding.

Conclusion

Design is an important component of good computer learning sequences. In this paper we have suggested some design standards.

COMPENDIUM OF BAD BUT COMMON PRACTICES IN COMPUTER BASED LEARNING

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This is an exciting era for those of us who have been working for many years with computer based learning. We are beginning to see commercially available products for aiding students to learn via computers. Many of these products are quite new. Unfortunately most (perhaps 90%) of these early modules are very poorly contrived.

At this early stage of the market, when almost any product brings sales, quality has not always been a determining factor in persuading people to market a product. Indeed, some marketers are already beginning to distinguish between their first generation materials and their better second generation computer based learning materials.

Users, however, often misunderstand this distinction and cannot distinguish the better materials. If we are to demand that vendors market higher quality material, users must develop a set of standards for examining material. This paper is directed toward the development of such standards for all users. We must beging to understand that any old learning material on the computer is not necessarily "good." I hope that my comments on judging material will be useful for developers of computer based learning materials; I discuss development in more detail elsewhere.[1]

The current situation, the poor quality of material commercial available, has great inherent danger. The problem is that the implicit inadequate standards promulgated by these poor materials may become *the* standard for computer based learning modules. If this hpapens, we will lose, perhaps for a long time, the real benefits of the computer in education.[2]

My tactic is to enumerate practices in computer based learning which are common but undesirable. Often these are practices which the novice does not note, but which are nevertheless worth discerning.

I will avoid pointing to specific examples from existing material. But readers may find it interesting and profitable to examine such examples by *applying* the ideas developed in this paper.

Content

Undoubtedly the most important consideration in judging any learning material is *content*. We are interested in material that aids learning, so that should be our primary focus. Is it substantial material, intended to accomplish some important learning function? Does it accomplish this function? A surprising amount of material, both comptuer and other, is very vague on issues of content; it is often unclear how learning material fits into existing or proposed new sequences of learning.

The most serious weaknesses in the content are what I shall call *trivial* pieces of material, learning material which is inconsequential. Limited segments of learning material, computer or otherwise, need not be infereior, but often is. A small amount of material may suggest a very exciting new approach to a particular area or to learning more generally. But the small computer programs currently availble for learning seldom do that. Indeed, they seem to have been developed primarily because the materials was "doable," easy and cheap to program, not because it has any serious learning purpose; thus, technology rather than education dominates.

One type of offender is the computer "game." At least two problems exist. First, this terminology is applied to almost anything. The word "game" is used to apply to activities that, as far as I can see, have no game-like aspects, assuming the everyday meaning of the word "game."

Another problem is that games seldom tie in well with specific learning situations. What is to be learned in playing an educational game is often vague to both student and designer. If they are true games, they often are strongly motivational. Although motivation is certainly extremely important in learning, it is not the whole story.

One could achieve similar motivation in some cases by bringing a pinball machine into class. One could then argue profoundly about how the students are intuitively learning information about the laws of motion in mechanics, particularly with regard to colliding objects; university faculty are skillful in making such arguments. I think these arguments would be weak, for sustained use of pinball machines. Educators need a clear

view about what is motivational with little educational value and what is motivational with strong educational value. Materials should be related to learning.

Games, I hasten to emphasize, can be extremely important in the learning process, more important than they are today. We must consider motivational issues. But we must develop games very skillfully if they are to incorporate learning issues. We cannot assume that anything called a "game" is automatically valuable.

Another area in much existing material where content in the learning sense is particularly weak is the type of help offered to students in difficulty. This is perhaps the most critical capability of good computer based learning material. Good students typically do not need such material. They can learn with almost any media. The real advantage of computers entails being able to give individualized aid to students who do have difficulty.

Yet much of the material one sees is inadequate for students in need of aid. The only help may be simply to tell students that they made errors, often in terms rather discouraging to the student. When "help" is offered, often it bears the guise of brief verbal advice, say, repeating a definition. Interactive help sequences, bringing users to understand the material and taking the time to determine if they do understand the material, are seldom available. Unfortunately, the typical help is s screen full of text, with no interaction, and details repeated that have already been stressed. "One level" help will be inadequate for many students; some may require quite different help in order facilitate learning.

The problem of inadequate aid for the learner in difficulty is related to a larger problem, the lack of individualization of the learning material. Different students learn best in different ways. Good computer based learning material assumes this, and provides a wide variety of learning sequences and styles. However, much current computer material provides only a single learning path, forcing everyone through the same approach in a lecture-like fashion.

I might summarize many of these bad practices in content by saying that much current comptuer based learning material devotes very little time--far too little--to considering the pedagogical details of the material. Much of it gives the impression that a quick pedagogical idea was generated, and then most of the energy went into the coding. Serious pedagogical material demands serious attention to the curriculum details, with or without computers.

Media Considerations

A developer of computer based learning material sometimes may have had experience in extensive curriculum development in other media; others are new developers without previous exprience. Many workers in this field will inevitably be people who have developed learning material in book form, in lecture form, or in other ways. Hence, it is not too surprising that, particularly in their early use of computer based learning, such developers tend to employ modes similar to those which drove their earlier activities. They are often still thinking implicitly about books or some other medium.

Developing a "feel" for a new learning medium, as we must do in the case of computers, is a heroic enterprise. We can give no very definite rules, since much of this activity depends on experience. But I will indicate a few of the media factors that characerize poor practices with computer based learning material.

Perhaps the central problem is the failure to recognize the potential of the computer as an interactive medium. Poor material has far too few interactions, too much for students to read on the screen before doing anything. Nontrivial interaction is the hallmark of good computer based learning material.

Although difficult, it is not impossible to establish criteria for "quality of interaction," a numerical measure, giving a rough feeling for the degree of interaction. One aspect of interaction, although by no means the only issue, is the time between interactions for the average user. There may well be an occasional situation in which the designer wants this interaction time to be long, perhaps as long as several minutes. Generally the average time between interactions (one interaction ends and another begins) should probably be more like 15 to 30 seconds. Sometimes we want it to be a good bit less than this. It is characteristic of poor material that the average time between interactions is too long, primarily because of excessive amounts of text.

A model can aid in developing such interactions. One can ask what good teachers do when they work individually or with a very small group of students. In such a situation most teachers will not "lecture," but will work interactively with the students, perhaps by asking questions. Learning must be an active process, if it is to be accomlished efficiently. Computers provide an excellent medium for such interactive learning. Readers interested in more details about interaction, including an early attempt to provide a numerical measure, may consult an earlier paper of the author.[3]

One bad practice, common with computers and with older learning media, is the inadequacy of visual or graphic information. Many students are not very skilled with language, and will only gradually build up language skills in courses. These students often need more visual aids in learning than is typically presented. Since teachers and developers of curriculum material *are* skilled in handling verbal information, they tend to use too much of it for many learners. We must insist, in examining curriculum material using computers and other media, on the necessity of providing sizable amounts of pictorial learning material. This information should be of direct help to the learner, not just visual "gimmicks." We *don't* want just a set of pretty pictures.

Another annoying feature of much computer based learning material is the constant repetition of stock phrases. In both simulations and problem generators a given section of computer code may be used over and over. This is often desirable, particularly when the material is embedded in a richer learning structure. But how undesirable it is to repeat over and over

exactly the same phrase, as students progress through the program! This is deplorable because it reduces the material to a mechanical procedure, whereas computers have the potential for engaging students in friendly dialog. A variety of simple tehcniques can easily avoid this impediment. For example, we can choose a phrase randomly from a collection of equally appropriate phrases for the particular situation. While this may seem to be a minor issue, attention to this can create material more appealing to students.

One media-related difficulty is the practice of solving "problems" associated with the learning maerial through other media. For example, my experience in making films discloses a tendency to believe that one should solve learning problems associated with the film by means of associated print material. Yet with most films, because of logistic or other problems, most students never *see* this associated printed material; so this way of trying to solve the problem is unsatisfactory. Similarly, a good unit of computer based learning material should, in most cases, *not* be highly dependent on print material, video, lectures, or other learning media.

It is poor practice to solve a pedagogical difficulty in learning material by resorting to another medium. I hasten to say that multimedia material itself, with each learning medium playing its full instructional role, is important in the learning process. But even when various media are effectively used, the logistic problems of making certain everyone has all the components at the right time can become difficult in the real world. Thus, laboratory material in the sciences for the first through the sixth grades, as in such projects a ESS and SCIS, has proved to be very difficult to use in practice, because teachers do not want to be bothered keeping and maintaining kits of material. In looking at computer based learning material, when I raise a pedagogical question and the developers of the material tell me they deal with that problem in the student notes or teacher notes, I have qualms.

Finally, one set of media-related problems seems important enough to discuss in a separate section. I next discuss the arrangement of material on the screen in both space and time.

Screen Design

As with other aspects of computer based learning, newcomers often treat the screen the same way they have treated "writing surfaces" in older media. Thus, the screen is considered like the page of a book or some other print-like format or a blackboard. Oten developers do not even know about print readability since that information is not used commonly in developing print material for learning. Perhaps the only curriculum development group to give adequate attention to the research literature on readability is The Open University in the United Kingdom.[4]

In some cases the computer-driven screen allows capabilities beyond those available on a page. For example, timing, by which material can develop in time to aid the reader's comprehension of that material, is not possible on a page of a book; when the learner turns the page the new material is all there, print and

pictures. But the screen situation being very different, material can develop in time. In other situations approaches possible in the book form are not *economically* desirable. One important influence upon a number of issues is that of blank space. Blank space in a book increases the cost of book; blank space on the computer screen is free.

Let me point to a series of readability factors common to both print and screen. Then let's look at some factors unique to the screen. Various studies show that these factors hurt readability, both in print and on screen, yet they are fairly common in print and computer material. The first is the use of very long lines of print. In general, the learner handles material better with short lines, although the readability results are rather complex. Right justificatin, combined with left justification, the common practice in books often cuts down on readability. Hypenation is a negative factor too; it is common practice, usually combined with right justification.

Keeping natural prases, defined either syntactically or semantically, together on a line also helps a learner who is not a good reader. While books have followed this practice occasionally, such as in the Leiber and Leiber popularizations of mathematics and science, it is still extremely rare in print material. It is almost equally rare in existing computer based learning material, although newer "second generation" learning material is beginning to show it. At present, to maintain phrases on the same line typically requires some human intervention; perhaps that is why it is not frequently implemented. At least from a syntactical point of view (not a semantic point of view), it could be automatic.

A number of useful ways to emphasize critical words and phrases in computer based learning material seldom appear in available material.

Some of these techniques for emphasis involve "moving" the material in some way, either turning it off and on--blinking--or oscillating it, or reversing field at some rate. Other techniques for emphasizing words and phrases will involve timing. Thus, one can pause a suitable length of time before and after a grammatical entity needing emphasis, just as one does in speaking. We can vary the rate of textual ouput for such entities, a topic we shall discuss later. Timing can also be effective in pausing after such punctuation marks as commas, semicolons, and periods.

One bad practice, almost universal with existing materials spews text at the user at the fastest possible rate, with no consideration as to whether this is desirable. In the Educational Technology Center for many years we have been examining this question informally and recently more formally. We find that very few users other than professionals like the fast rate typical of material today. Instead, "normal" users, given a choice, use a rate much like the 300 baud rate of communications. In interviewing users, we have found that the fast rate is disturbing to many. One of our current research projects is attempting to gather more detailed information about this issue. Our previous experience make it clear to us that text is usually displayed too rapidly for most users of the sytem, another very common bad practice.

Although we currently set the initial speed of materials at what we consider the best desirable rate, very uncommon in computer based learning material, we also believe it is desirable to allow learners to control the rate of text output at any time. This raises an issue of an entire set of factors for user control of the screen. One of the computer's advantages is that it allows such reader control, which is not possible in text material. Yet developers commonly ignore this possibility and provide no more control than is available in books. Users can employ a number of controls with computer based learning material. Bad practice is not to allow such controls.

The handling of input is often particularly bad. Long inputs, with much English text, frequently lead to words split at the edge of the screen. That is, when the print gets to the edge of the screen, the hardware or software shifts part of the word to the next line. The edge, however, is not necessarily the critical location. One might prefer a word not to overlap a diagram or other text, and so provide controls that prevent such overlap, while assuming that a whole word is on one line. Strategies for not splitting words are well-known in computing; they are used widely in word processing systems, where they are typically called "word wrap." Words crossing lines or words overlapping with diagrams or others, particularly on long inputs, is a frequently seen but highly undesirable practice. Like many bad practices, relatively minor increments in the software can control it. The difficulty is that input and output provided by most computer languages is quite inadequate.

Perhaps the worst among a number of bad practices associated with student input are the types which allow a program to bomb because of a mistake, such as typing a letter instead of a number. Such typing mistakes are common, particularly with a novice likely to confuse the numbers one and zero with the letters "l" and "O." Fingers resting lightly on the keyboard can "add" characters not intended. For some time special "font ends" for novices have provided coding for input which supercedes the rather crude input now provided in most computer languages. Many current materials do not provide such user-friendly front ends.

Another useful but rarely available feature for student input is the timed read. In many situations it is undesirable to let a learner sit indefinitely long before the computer does something. Learners may not really understand that they are expected to type something at that point or may have no clear view of what to type or may have typed something without pressing return. In all these cases timed input can carefully handle the situation.

Weak underlying software is likely to generate bad practices in computer based learning by poorly designed placement of text on the screen. Most computer languages make the book-like assumption that text should always start at the left-hand margin. I consider this a very bad practice, seldom desirable. Text should appear on the screen by conscious design to best aid learners with that particular component of text.

Finally, text should frequently disappear from the screen without erasing information which is still relevant. Text no longer applicable to the situation at hand shouldn't be there. Modern systems allow ports to the screen to be removed, without affecting other parts of the screen. In much current computer based learning material at any one time the screen shows a past history of what has happened, often with irrelevant text for the current situation. The practice of removing superfluous text, concentrating the student's attention on what is currently relevant, relates to the frequent use of blank space mentioned earlier.

Other Factors

Other issues should be mentioned which fit either loosely or not at all in the classifications developed. Some have to do with tactics used in the materials. A number of tactics are poor tactics, but commonly used.

One such undesirable tactic is multiple choice questions, particularly in on-line quzzes. In some cases this is a subconscious choice. People know that multiple choice has something to do with computers, so they focus on it when they start to develop interactive computer materials. Some computer quizzing systems for both off-line and on-line employ primarily multiple choice.

Multiple choice should, I believe, almost never occur in computer based learning material for two reasons. First, mutiple choice is a poor way of determining what a learner knows. Guessing factors play too sizable a role. Further, this mode of quizzing fell into education as a tactic of desperation, using relatively crude early technology to handle large numbers of students. It has little to recommend it at present. Better technology renders it obsolete. It is not needed with a comptuer for we can ask a much wider range of questions which avoid guessing factors, and so lead more quickly to reliable information about what students do and do not know.

A number of departures from ordinary English also fall into the category of bad practice. Some are hard to understand. For example, often *immediately* after the question mark, with no intervening spaces, the computer pauses for a reply to a question. The display is certainly not characteristic of the way we teach people to write English!

Also common is the widespread use of Y's and N's, or even worse 1's and 0's, in place of "yes" and "no." While some use of single letter mnemonics may be useful it is an undesirable tactic to follow in most computer based learning material. Future displays, such as those currently in use in Sesame Place, may build yes and no keys directly onto the display. At least in this case the full word is there, not some computerized abbreviation.

As stated earlier, I aspire to urge upon the developers and publishers of computer ased learning material some standards of quality. And I wish to suggest to users of computer based learning material the possiblity of reasonable judgments concerning the quality of that material. Many important positive issues in the development of computer based learning material are

not tapped. For further details the reader can consult a recent book by the author, *Learning with Computers*.[5]

I welcome comments about bad practices from others to add to my list.

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COMPUTERS AND THE FUTURE: EDUCATION

FOR CAL83 PROCEEDINGS - University of Bristol

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It is a pleasure to return to England to give this keynote address. During my stay as advisor to the National Development Programme in Computer Assisted Learning, I attended an early CAL meeting at Oxford; I met many of you and learned about ongoing projects. This trip renews many old acquaintances. Perhaps I haven't been in England frequently enough since then. The gentleman at Passport Control at Gatwick commented, "You have been neglecting us--you haven't been here since 1980." I will try to do better in the future!

This paper has four components. I begin with a series of assertions about computers in education, some supported later in the paper. I then review two examples of computers in education developed at the Educational Technology Center. A brief interlude considers the major advantages of the computer in learning. Finally I speculate on the future of the computer in education, arguing that it will be eventually the dominant delivery device for all areas of education. I consider aspects of what will happen.

Some Assertions

The following statements will not be defended in this paper. I wish to make my position clear on these issues.

1. Extremely little good computer based learning material is available in any country. Much of the material, including commercially published material, is of very poor quality.
2. The standards currently in use in computer based learning material are extremely low and are in great danger of becoming accepted as the standards.
3. Many of the materials available are bits and pieces rather than coherent collections of learning material.
4. The computer can be used in many ways in education. Philosophical discussions should not rule out certain ways. Decisions should be made on pedagogical grounds.
5. The training of teachers is a major weakness in our current systems. Most of the present in-service ways of training teachers are entirely inadequate to the task.
6. In teaching programming at any level--primary school, secondary school, or college or university--the major emphasis should be on teaching good modern programming structure.
7. It is very unlikely that good programming courses will be taught in BASIC. BASIC should be avoided at all costs.
8. Authoring languages are useless in generating effective computer based learning material.

Readers who would like to discuss these issues with me further are welcome to do so.

Two Examples of Computer Based Learning

To give some reality to the notion of using the computer in education, I discuss in this section two examples developed at the Educational Technology Center, described elsewhere in detail.

1. Introductory Physics Quarter

About seven years ago we developed the mechanics part of an introductory physics course, based on highly interactive, graphic, on-line tests. This course has been used about five times, with 2,000 students, and improved. We are now discussing moving a subset of these tests to personal computers for marketing.

The pedagogical structure of the course is like a Keller plan, Personalized System of Instruction, or mastery course. The subject matter is divided into units; students stay with a given unit until they perform almost perfectly on tests associated with that unit. If a student shows weaknesses on a test, further study is required. Eventually the student takes another test version covering the same learning objectives.

Tests are given on-line at the computer. In the typical presentation 400 students chose one of the two computer forms, which differ in content. About 150 students chose a standard, noncomputer variant of the course. The 400 students who choose computer versions take about 15,000 on-line exams in ten weeks, with the computer generating each exam uniquely, offering immediate and very detailed feedback and help to students and doing all the record keeping. Because of the highly relevent student assistance, students agreed almost unamimously that the quizzes are the main learning material in the course. So we describe this course as quiz-based.

While this is a physics course, the technique of structuring a computer based course around the quizzes with little additional expository material is extremely promising for the future.

2. Scientific Literacy

The second set of units were designed several years ago, when the Educational Technology first employed personal computers. These computer based learning dialogs are about one and a half to two hours long for a typical user.

Although the units are in the context of science or mathematics, their main objective is not to teach the subject matter but rather to bring a wide audience to a broad but deep understanding of the nature of scientific activity. Such issues as what constitutes a theory in science and how theories are discovered are the main content issues, though not discussed explicitly.

The programs are divided into modules, typically eight, each about fifteen minutes long. Students can enter any module and thus do not need to finish at a single session. Students as young as ten years old as well as university students and adult learners have used many of the progams successfully. Indeed, we know of no other way of teaching these difficult issues that potentially may be as successful. Full summative evaluation based on the objectives has yet to be carried out.

Repeated extensive formative evaluations have led to improving the units. These took place in schools with children about twelve years old through university environments and in public libraries.

In the public library a computer message invites anyone to use it. No one helps students with either the computer or subject matter. The materials are self-contained, a complete learning experience on the computer. Testing in libraries has many advantages, including noting places where the materials are motivationally weak and in need of improvement.

These examples do not exhaust the ways computers can aid learning. They show contrasting mainline instruction where the computer plays a very important role. Other examples, from the Educational Technology Center and from other groups illustrate other modes.

Why the Computer in Learning

Why is it that the computer is destined to be such an important factor in human learning at all levels with all types of people? Fundamentally the major factor is *interaction*. The fact that the computer can make learning an *active* as opposed to a passive process implies other important consequences.

What does the learner do during the learning process? The model of learning implicit in present school-based education is the *passive* model. Information is "delivered" by the teacher or by books, and the learner is a passive absorber of that information, a spectator. Learning must be active if ideas, methods, concepts are to be internalized. To be useful to the individual, learning must involve some activity on the part of the learner. A learner, or small group of learners, working with a human tutor, can maintain such activity. But most of our current learning situations, where many people need to learn and limited funds support learning institutions, are passive.

The computer allows us to move away from spectator learning at reasonable cost and to return to interactive learning for everyone. This is not to say that the computer competes well with an extremely good tutor. We can, with computers, become more interactive than is *usually possible*.

Once we accept that the computer can make learning interactive, even with large numbers of students, we see some consequences. As the computer can query the student, frequently we can determine what the student knows. So the curriculum modules can be adapted to different backgrounds, without any conscious realization on the part of students. We can fill in missing background material or methods. After presentation of new ideas, the program can check using internal quizzes to see if the student comprehends. If not, the presentation can be reviewed or new approaches to that material can be offered to the student. Thus, learning can become highly individualized, differing for each student in terms of the learning materials and the time.

Another consequence of interaction is that we can determine the level of interest of the student. While this is more difficult to do, it is possible in an interactive environment. Material that is weak in interest can be changed, following a different approach.

Because of interaction we have very powerful mechanisms for improving the material. We can save student responses; these responses give us extremely detailed views of what is happening with students moment by moment.

Although the computer allows this highly interactive approach, with various benefits following, not all computer based learning material is interactive. We need to develop standards for judging the quality of interaction. Often beginning users, both students and their teachers, are satisfied with very weak forms of interaction, because it is such an improvement over noninteractive learning media. Thus, many of the videodisc plus computer modules produced so far, often by video people, are extremely weak with regard to interaction.

The Future of Education

In this section I briefly discuss four important issues concerning the future of education, as affected by computers.

1. Widespread Future Use of Computers in Education

It seems almost certain that the computer will be used very widely in education, not only in formal schools--primary and secondary and university--but also in training and in adult education. Two issues assure this: (1) The effectiveness of the computer in education and (2) the economics of computers in education. The effectiveness follows primarily from interaction and individualization. The economic issues are even more obvious. Computers, particularly personal computers, are declining rapidly in cost. Furthermore, many companies, publishers, computer vendors, and new companies are moving toward

developing and marketing computer based learning material. While much confusion exists in direction, the total commercial funding in this activity is sizable and growing. These companies recognize that a large market will develop, even though at present they are very uncertain about the nature of the market and uncertain of their role. I refer to these two issues as the "good and bad" reasons for the widespread use of computers in education.

2. The Future of Education Will Not Necessarily Be Desirable

It should be made clear that at this time it is not clear whether the computer will lead to a better or worse educational system than we have today. Like any powerful new technology, computers can be used in either desirable or undesirable ways.

Presently, the very poor computer based learning material available is setting a very low standard. If teachers, administrators, and parents continue to accept this low standard, it may become the standard. So we may move toward a future with very poor ways of using the computer in education, ways which lead to undesirable learning.

3. The Key to a Good Educational Future is an Effective Production System

The questions of how and where materials will be produced is critical in determining whether computers will aid or retard education. If we produce computer based learning material with care, the same care which has gone into major curriculum projects such as those at The Open University or the major efforts in the United States in the 60's and early 70's, then we can expect the computer to lead to a better educational system. However, if we continue with the current cottage industry structure, with teachers producing little odds and ends of material with little coherence and little classroom testing, then we will be in difficulty. The next five to ten years are the critical period.

4. Institutional Change Will Be a Critical Part of the Future of the Computer in Education

Given the major changes which will occur in education, we cannot expect our educational institutions to stay the same. Schools and universities will change their nature in ways which are not entirely predictable at present. Much of the pressure for these changes will not come from within; educational institutions are conservative and do not change drastically without strong external pressures, including monetary ones. These pressures will become stronger, and so we can expect institutions to change. Distance learning activities will increase in importance, even in the elementary and secondary schools. Mastery or criterion reference modes will become more common. The time to move through educational institutions will change and will be more varied than at present. There will be many other changes. I am predicating that the future of education is a desirable one. The changes for an undesirable future are frightening.

The only way we can move toward better educational systems is by efforts of all of us. The time for this effort is now.

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A TALE

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Once upon a time ....

there was a marvelous invention, almost comparable to the gift of fire to humankind, except that it was the product of people's minds. It was a revolutionary invention, changing profoundly many aspects of human life. Eventually it made possible a new way to learn, a way which quickly superceded earlier ways.

This marvelous new invention was not created for purposes of education, so at first teachers ignored it completely. Nevertheless teachers around the world heard of the invention, and the imaginative ones soon recognized this marvelous invention's great potential for education, and they wanted very much to use it with *their* students, eager to benefit from the excting new technology. But for many years such teachers were frustrated perhaps because among the great invention's many purposes education was of low priority.

The most innovative teachers, brave souls that they were, found it possible to buy the new device, and they set about trying to use it. These teachers produced some materials for their own students, and shared a limited number of these materials with others, even though their products were only amateur efforts. After all, they were primarily *teachers*, specialists in education; they were not at ease with this new and esoteric technology. Yet they were brave pioneers doing their best to use the magnificent invention to aid learning.

As the new invention became better established, there arose a group of specialists particularly talented in using the new invention. A few of these specialists were also interested in education, so they too thought about the invention's role in learning. They proposed a few products, but their efforts were only minimally useful. These specialists understood little about teaching and learning, even though they were experts at the wonderful invention.

Most teachers still avoided producing educational material by means of the invention. Some were scornful, saying that the new technical development had nothing to do with education. This was not surprising, considering that teachers number many conservatives among their group who tend to believe that their long standing techniques must be the best. Furthermore, teachers recognized that some of the early products of the new invention were of poor quality.

Many years elapsed, with occasional educational experiments by teachers or specialists. Occasionally a bold experiment produced a better educational product, but most products were not very useful for students. The potential of the marvelous invention remained unimplemented for education.

Then a few people began to see a better way to proceed. The notion evolved that several persons could collaborate in developing educational products based upon the marvelous new invention. Teachers could use their special skills to aid the learning process, and technological specialists could devote themselves to the production. So a production system emerged combining the talents of both types of experts. Gradually they recognized others who could signficantly contribute to these educational materials. Artists provided pictures and other elements of design.

As they produced more educational products using the marvelous invention, the world began to accept the idea that these new learning materials could be important in education. Companies sprang up, aware that the public would buy this new product because of its aid to education.

The market grew slowly. But eventually the educational products based on the wonderful invention appeared everywhere. They led to a revolutionary new stage of education, new ways for people to learn.

The marvelous invention was ....

the printing press.

Or was it the computer?

COMPUTER ASSISTED LEARNING--THE AGE OF REASON

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The newer uses of the computer in education have fully demonstrated that the computer is an extremely powerful learning device, one that has potentials far beyond those available in current modes of learning, such as lectures and textbook. The major advantages of the computer, its interactive capabilities, creating an active learning experience for everybody, and the ability, because of interaction, to individualize the learning experience to each learner, even with very large numbers of learners, are now understood. We also are beginning to understand the process for developing computer based learning material, the set of steps which will lead from the earliest ideas to finished tested material, either for schools, universities, for adult education, or for training.

However, knowing how to do these things, knowing the capabilities, is a far cry from insuring that they will really happen. The computer, like any other piece of technology, does not inherently contain within itself the reasonable ways to use it. In fact, all technologies can be used poorly or they can be used well. Most of the learning sequences on computers that are being produced now, at all levels, are poor, not at all reflecting the full capabilities of the computer.

Hence, the issue of whether the computer will improve education training is still to be decided. The computer can lead to a worse educational and training system than we now have. The problem is world wide, demanding cooperation among all countries if we are to move toward highly desirable educational futures. The transition to computer based learning systems is already upon us and can be expected to accelerate rapidly. In addition to the economic benefits resulting in schools and training institutions with the use of the computer, more and more apparent as the computer drops rapidly in cost, there are also powerful commercial reasons involved, large companies that see the computer already as an important market. The use of computers in education is no longer an academic issue, one that can be debated in learned meetings; rather it is a practical issue we must address with all speed.

This paper is structured in three sections. In the first section I consider some existing examples of computer based learning material. While these are described only briefly in this paper, in the talk they will be illustrated in more detail. It is difficult to write about computer based learning. In fact, the best possibility is for the readers to work with programs such as the ones described here. In the second section I consider the strategies for producing computer based learning material that have been developed at the Educational Technology Center. In the third section I consider some of the future possibilities with regard to computers in education and training. In all these sections, the discussion will of necessity be brief, far less than is deserved by these important topics, considering that the future of education is the issue that we face.

EXAMPLES

I mention several examples of material that has been developed at the University of California, Irvine, in the Educational Technology Center. These examples illustrate quickly some of the range of current possibilities.

The first example is beginning quarter of an introductory physics course. This course, in its computer form (students have a choice of a non-computer version also) consists of about 15 on-line quizzes. Quizzes are used in a mastery mode; a student must perform essentially perfectly on a given quiz or take another version of that quiz over again. The student who takes a quiz 4 times and does not succeed, must see the teacher for individualized help before proceeding.

The learning material is built into the quizzes. For most students, this is all the learning material required for the course. The quizzes can often determine exactly what problems the student has. We like to refer to a course of this kind as a quiz-based course because, unlike the standard course, it puts the focus of the course on quizzes rather than on didactic learning material.

Attention is also given to building up students intuition with a "controllable world," allowing the students to "play" with mechanical phenomena with workbook sections that discuss exactly what should be done.

We give approximately 15,000 quizzes during ten weeks. A student spends an average of about 2 1/2 hours a week on the computer. About 400 students take the computer based course. I should also indicate that there are really two computer based courses with quite different quizzes; the student is offered a choice of content as well as other learner control factors.

As a second example, I mention a set of materials which were developed to aid students in understanding the nature of science. These materials, developed more recently for personal computers, address important issues of the essence of scientific theories, working with a wide variety of students from eleven years through sixty years, in a variety of situations. They have been widely tested, not only in schools, but also in public libraries and science museums. A typical unit in this case lasts about 90 to 120 minutes. The strategy is to put students in a position where they must behave like a scientist.

A third project I will mention, just in its early stages, concerns the question of teacher preparation. As computers appear more and more rapidly in schools, massive problems develop with regard to how the teachers are to use these new devices. The traditional methods of teacher training are inadequate to the problem, given the numbers of teachers and the speed necessary. Few teachers in any part of the world are close to centers that can give adequate aid. We believe that the only way to tackle this problem is through the use of the computer itself. We have developed several modules and are seeking funding for others. Our hope eventually is to produce a full-scale set of materials for teachers covering all aspects of the computer in education, modules that can be used by all teachers anywhere the problem is very urgent.

A PRODUCTION SYSTEM

In this system I describe a system for producing computer based learning material. This system is aimed at producing high quality material, at a time when sizable amounts of material must be produced, a few years from now. The production system draws upon the experiences of other sizable curriculum development efforts in recent years, involving a wide variety of other media. Thus, the strategies used are, in many ways, similar in overall form to those at The Open University in England, the world's foremost developers of university level curriculum material. I will briefly describe a number of stages. Again, details cannot be presented in such a brief time.

Stage 1--In any project the initial stage is the decision to produce the material which usually involves securing the funding also.

Stage 2--There must be an overall design of the project, describing in some detail each of the modules to be produced. One way of developing this overall design is through a meeting of national, or international, experts in the area, including teachers with practical experience. This group, through brainstorming and other techniques, is asked to come up with the descriptors, perhaps a page or so of each of the units to be produced.

Stage 3--The overall design can now be reviewed and perhaps modified, based on these reviews.

Stage 4--Detailed pedagogical design follows. Each of the units of the course needs to be fully specified. The result of this stage is a script, something like the manuscript of a book, a storybook and shooting script of a film, or other descriptions of this kind. All the pedagogical details, including the complete analysis of student responses, must be given. The computer has its own form of script, different than a film or book.

Stage 5--The script can also then be reviewed by a variety of experts, and changes can be made.

Stage 6--An important issue in computer based learning is the way information is displayed on the screen, the design of the screen. The computer is not a book offering different kinds of controls in space and time, as to how material is on the screen. Some of these are controllable by the user, others by the programmers. A competent graphic designer is needed to establish the design.

Stage 7--The screen design can now be reviewed and possibly improved.

Stage 8--Before coding takes place in a modern software engineering environment, it should be designed. A variety of strategies are available for doing this. Design of the code is much more likely to produce a code which will be easy to modify, maintain, and transport.

Stage 9--The code design can then be reviewed.

Stage 10--At this stage coding can now take place. Note that many stages have preceeded coding. Inadequate structures for developing computer based learning material often put the coding process much too early.

Stage 11--The code itself can now be reveiwed, to see that it actually satisfies the standards of good, modern coding. Again, this is important if the material is to be modified in later stages.

Stage 12--Next the actual running of the program can be reviewed internally in the project. At this stage we find that if the program does what it is supposed to do. Many changes are suggested; the program is now viewable on the screen, and some of the ideas which seemed reasonable on paper do not seem desirable in the running material.

Stage 13--We can now conduct a series of formative evaluations, perhaps with increasing numbers of students, and revisions following each of these formative evaluation stages. This is one of the most important stages in the process. For the first time, the actual students are using the material. One of the advantages of computer based learning material is that we can gather very detailed information about how students are behaving, and we can use this information for significant improvements in the performance of the learning material.

Stage 14--Finally we might conduct, if funds allow, a full-scale summative evaluation of the material. But we seldom have adequate funds for a full-scale summative evaluation. If such an evaluation is conducted, it is probably best to do it some years after the materials are in use, so that minor bugs of usage can be removed and do not interfere with the major issue of the evaluation.

I stress that I do not believe that some of the "short cuts" that have been suggested, strategies which try to shorten this process, are adequate. The process just described will be seen to be, as already noted, similar to good strategies for curriculum development in other media, too. In particular, I strongly recommend again the use of authoring languages and systems. While this practice is widespread, and new systems of this kind continue to be developed all over the world, the study of the products of such systems, as compared to material that is produced without authoring systems, suggest that these systems seldom lead to first rate material. A group that starts out to develop a new authoring capability always "knows" that there was something wrong with previous ones but feels that they will be able to correct the problems. The difficulty lies not with a particular authoring language or system, but with the whole notion.

FUTURE

The massive changes in our educational systems, implied by the computer, in all levels and in all types of educational institutions, cannot happen smoothly. Particularly, it seems unlikely that there will be any careful planning. What is more likely to happen is that various types of traditional schools and institutions will try to preserve their present strategies, always fighting rear guard actions to maintain essentially the status quo, hoping that the computer will make only minor changes and additions to their program. As it becomes more and more obvious that the changes will be major and that the entire structure of institutions must be changed, it is likely that the situation will become more and more difficult.

Many questions are raised. One question is that of the arena for education. At the university level, the success of learning at a distance institutions has already shown that good reasons exist for moving some, or all, of traditional university education to the home, or to the home plus public environments such as learning centers. In the schools and in training, distance learning activities are likely to play a much larger role than they do at the present time.

The computer does not demand that it be used in any particular physical location. It can be used in any home or in any other establishment. So the possibilities for learning become very much enlarged. If systems such as voucher systems come into widespread usage, and commercial vendors enter the primary and secondary markets, then this will also change the nature of education.

Another interesting feature to consider is how the shape of courses will change. Not only will there be more computer usage, but it seems likely that self pacing and mastery stragegies, with each student proceeding at a pace natural to that student, will become much more common. The lockstep education of today which assumes that everybody must be at the same place at the same time, true not only in countries with centralized educational systems but also effectively true in countries with decentralized systems, is likely to change.

Even more striking may be the changes in content. It is clear that as the computer becomes more and more a part of our society with powerful enabling tools playing a major role, the content of courses will change. Does anyone still need to learn to differentiate and integrate, for example, if it is all to be done in the future via computer? As the computer is becoming more and more powerful as a learning device, new and more powerful computer tools will be created which will transform the need for various types of learning. So course content will change almost as rapidly as course form during this period of time.

A third factor will be the question of what happens to institutions. We have already indicated that they will of necessity change, even though they are likely to resist change. It is easy to take on the form of the new educational strategy but harder to deal with the substance. For example, those colleges which are currently moving to having large numbers of computers available on campus have so far given relatively little thought to the issue of how curriculum will be affected. Indeed, there seems to be an assumption that "our faculty will do it." Yet, frankly, faculty in the United States and many other parts of the world, have almost no experience in curriculum development. They were not picked as faculty because of that experience, and it seems unlikely that they will be able to make major changes in their courses by themselves.

The next issue then, naturally suggested by the previous one, is where all the new learning material is going to come from, who will pay for it, by what process will it be developed--the process shown here or by some other process. Will the actual production be under control of commercial forces or will the educational establishment, or some parts of governments, have at least some say in the matter? We almost lost the possibility of using the video technology in any useful way in education because of the commercial pressures. It is not clear what is going to happen in this situation at the present time, but the stakes are large. The period ahead will be, for all of us, a very interesting time, and the future of education depends on what happens.

FAMILIES, COMPUTERS, LEARNING

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The Educational Technology Center is a research and development group concerned with computer based learning at the University of California, on the Irvine campus. Several years ago, we received a grant from the Fund for the Improvement for Post-Secondary Education, within the Department of Education, to develop science literacy units for a very wide general audience. One of the tenets of the project was that the material should be usable in public libraries. We had looked for funding for computer based learning material to use in public libraries for several years, and finally we were successful. We developed about a dozen hours of material for this environment and a similar amount of material on another project which also was tested in public libraries, as well as in schools. I will not describe the nature of either of these two projects, amply described in literature available from the Educational Technology Center.[1]

A number of interesting features were found in our use of computers in libraries. Unlike some uses in libraries, we were not providing computers for kids to play games or for people to learn to program. Rather, we were providing highly interactive computer based learning material. Because the material was in the libraries, it had to run completely stand-alone with no teachers or others to help, either with computer or subject matter details. Furthermore, the material had to be self-motivating, holding the interest of the student, since library visitors leave if they lose interest.

One feature that we noted in libraries, which we found unexpectedly, was that we often had families working together on running the material. We saw many examples, but we did not count the number of such family examples. A typical arrangement might involve a mother, a father, and two children. Sometimes the children were even too young to read; the older children or the parents would patiently ready to them, and then there would be a discussion about how to reply. One of the literate members would type in the reply. We saw far more of this than we expected; we were not encouraging it in any way that we were aware of.

When I observed families working together at the displays, it was clear that a joint learning activity was going on. All the people involved were learning something, and part of this learning was coming through the interaction of family members with each other, stimulated and motivated by the interaction with the computer. Thus, we seemed to be promoting a type of family "togetherness," unexpected for us.

Parents do traditionally help their children with school work. When the children have trouble with homework, they will, at least in some families, appeal to the parents. But this interaction is often unsatisfactory. The learning activity is often, at least in pretense, one that involves only the kids. The parents often try to maintain the attitude that they "know," because of their own school days.

Projects which have explicityly presented kids with material that their parents didn't know have often run into parental opposition. The most interesting example of this kind was with the new mathematics. Few parents had any experience with such topics as different number systems, and the more rational explanations of long division. Schools quickly realized this, and so some classes were run to acquaint parents with the new mathematics. But these were only partially successful. I would not claim that the unfamiliarity of parents with the new math is the only reason that they new mathematics had such difficulty in the American school systems, but it probably played some role. In any case, homework is seldom viewed as a joint learning activity by both parents and the children.

Yet in our society we hear much discussion of life-long learning. Educators argue that knowledgable adults must continue to learn all their lives. Adults do engage in a variety of learning activities, everything from formal courses, such as in a community college, to visits to the public library to obtain books in a particular area to learn something about that discipline. As society has changed more rapidly, the need for continuing education has become more and more pressing.

I do not know why we saw so many examples of the family learning together with our materials in the public library. The materials did address a very wide age group, because they were intended to be not only for children but also for adult education. The subject which they dealth with, the nature of scientific activity, is one that is seldom understood by people of any age in our society, even though the society is scientifically and technologically based.

It is perhaps dangerous to draw conclusions from the few weeks in public library that we observed. It could be that our family usage was something of a statistical oddity. But I think rather, that we may have a clue to a new educational process for the future. As the computer is used more in our society, and as it becomes more accessible in environments in which the family can work together in learning, we may see more learning together activities in the family life.

A number of factors are necessary if this is to happen. First, sophisticated learning computers must become widely available to the general public, not only in such areas as public libraries, but perhaps even more important, within the home. Today's home computers are generally too weak to allow the types of learning that are likely to be important.

The second ingredient necessary is the development of effective curriculum material, learning units which employ the full interactive and individualized capabilities of the computer. If these are to be widely used by both the parent and the students, the formative evaluation process must work with both types of audiences, including family audiences. Public library environments provide a very useful way of doing that, based on our past experiences. The subject matter of these programs must be serious. That is, if the material "plays down" to young children, it probably will not be that exciting to parents. We _can_ write learning material that _does_ appeal effectively to both age levels, at least in a very wide variety of subject areas. But this will happen only if we have much more serious efforts at curriculum development than we presently have.

A third implication is that, as our educational systems change under the impact of computing, more and more of education, at least education concerned with knowledge based learning, will take place in the _home_ rather than in the school or university environment as it does today. I do not wish to imply that schools will cease to exist entirely. Although that is a possibility, I do not regard it as likely. Rather, certain components of education will migrate to the homes and other components to stay in the school. One example might have the kind of split that is seen in George Leonard's _Education and Ecstasy_, knowledge based component and socialization components. If we view Leonard's knowldege based activities in terms of today's and tomorrow's personal computers, it seems clear that much of it _could_ take place in the home if adequate materials were available.

Finally, I point out that there may be a number of interesting sociological consequences of families learning together in addition to the obvious learning benefits on both sides. Parents will be able to exert a greater degree of control over their child's learning environment. I do not, frankly, know how desirable this will be. It could lead to social problems, or it could lead to a very interesting, pleasant, new form of society.

I emphasize that the evolution toward families learning together with computers is likely to be one that will take considerable time. It will not happen tomorrow. But it does present very interesting possibilities for the future of education.

Using Computers in Training - Getting Started
A-5

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One aspect of the American educational system which has increased greatly in recent years, and shows signs of growing even larger, is industrial training. These activities include internal training of engineers and other personnel and customer training conducted by the company. In large corporations these training activities can be very extensive, often covering many areas common to schools and universities.

It is interesting to speculate why industrial training continues to grow at a time when other types of educational institutions in our society, such as schools and universities, are static or diminishing. One factor in this growth is a general unrest about the products of our educational system, found in many places; a strong feeling exists that if companies are to survive and flourish, they must do more training of their own personnel.

If a company has products specific to that company and various people need to use and maintain those products, those people must be trained. In other cases increasing training activity represents underlying unhappiness with traditional education. Many companies, explicitly or implicitly, have simply "given up" on the traditional educational system to a startling degree. This situation has become common, reflecting the widespread distsrust of our educational system.

The reasons for this increase in training are not the major concern of this paper. Rather, I wish to examine the decisions involved in beginning to use computer based methods within training activities. Relatively little computer based material is currently used in training, particularly if one excepts a few large companies that have pioneered this area. Most industiral training is based on books and lectures, as with traditional education. The potential for computer based training is great, and almost every sizable industrial training activity is now investigating the possibilities of the computer in learning.

The computer is a powerful device in any type of learning, either in training or in more traditional educational activities. Good computer based learning material has distinct advantages over other ways of delivering education. Hence, we find a growing realization that computer based learning will play an important part, perhaps even a dominant part, in the training systems of the future. This paper will not attempt to review the considerable advantages of the computer but will assume that interest in computer usage already exists. It raises the question of how to begin, not the question whether one should begin at all.

The Scale of the Beginning Project

The first decision that must be reached, if one is to develop training material using the computer, is the scale of the initial project. That is, how large a computer based project is contemplated.

The project should not be too large because that would involve great costs in an uncertain direction for the company. Many factors associated with computer based learning can only be determined after some experience. Hence, a project which starts out with the notion of moving all training immediately to the computer is not realistic.

On the other hand, a project can be too small to yield any effective information about the use of a learning mode. Thus a small segment of a course is likely to be of little use in understanding the computer and its application in a particular training environment. A reasonable place to start is with a whole course, probably a brief course.

Picking a course already in existence is one possibility. Another possibility, perhaps better, given developmental time, would be to develop training material related to a new course, perhaps training in use or maintenance of a product which is currently under development and not yet released. If a "conventional" course already exists, the new computer based course has a standard of comparison. However, anyone who takes this direction should understand that comparing two courses with different instructional materials is a difficult and expensive activity, often beyond the resources of any expect very large concerns.

FACTORS IN CHOOSING A PILOT COURSE

The initial project, the beginning pilot course, must consider several factors. First, the group is developing experience about how computers can be effectively used within the training group, a major reason for developing the course. Second, this project will be important to convince management they should proceed further with the development of training materials involving the computer. As all good computer learning materials are likely to be expensive, having a clear mandate from management is important.

A number of considerations should be kept in mind in choosing the pilot course. I describe each briefly. Not all will be applicable in each situation.

1. The Course is Given in Many Locations. One of the advantages of computer based learning material is that, because of small personal computers, it can be offered almost anywhere electricity is available. Hence, we do not need to bring people to a central location, often at considerable expense. Many companies have centralized their learning activities, building large learning centers in a few places. But often the curriculum materials should be available in field offices and sometimes at the customer's site. Computer based material lends itself very well to such possibilities, so this factor is important when using the computer in learning.

2. An Interactive Learning Experience is Highly Desirable. This factor is critical in computer based learning material. No other mode of learning, available to many people, provides a level of interactivity possible with good computer based learning material, except human instructors working with very small groups.

In computer based learning material students frequently can be queried to see what they know and appropriate action taken. Indeed, students can answer a question perhaps once every 15 to 20 seconds in good material. The experience is very different for the majority of students from listening to someone talk or reading a book. While a few very good learners can create active experiences out of these situations, most learners cannot. The computer brings interactive learning to almost everyone, but only if the course is designed to take this into account.

3. Individualization is Important. In many situations students already know some material. For efficient learning, students should be able to work on what they do not know and be able to bypass quickly material they do know. In an interactive environment, such as that provided by the computer, we can determine, by built-in quiz segments, at each stage exactly what the learner knows and just what additional help the learner needs. So the program can be highly individualized, tailored to the needs of a particular learner. This is clearly very important when learners come from many backgrounds and is also important when taking into account the rate at which different students learn.

4. It is Desirable to Save Time. In typical training situations students who are employees of the company are removed from usual routines to undergo the training activity. This means they are not functioning as productive individuals within the company. Hence, the sooner the training is completed, the quicker they can get back to a productive job. In a sense, in

most industrial training, the time spent in training represents money to the company, so briefer time corresponds to less cost to the company.

Because of the possibilities of individualization the computer often cuts down on the amount of time needed for training a particular student. Students can proceed at their own pace, and experimentation indicates there is often a gain of about 25% in saving of student's time. This suggests an important factor in choosing the prototype course would be to pick a course where the time of the participants is very valuable to the company. If tt can be shown that these valuable students are spending considerably less time with the computer based material than with some other approach, a strong economic argument is made for the computer material.

5. Expensive Equipment is Involved. Another factor suggesting a particular prototype course is one learning to use the expensive equipment. Thus, the course might consist of training people to use an expensive graphics output device. The more work time required for students to use the actual equipment, the more expensive the course.

Often it is possible to simulate on personal computers some or all of the components of the equipment. If this can be done on relatively inexpensive computers, the need for learners to tie up expensive equipment for lengthy times can be lessened greatly.